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Effects of physical workload on working memory performance

신체적 부하가 작업기억 과업 수행능력에 미치는 영향

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Abstract

Effects of physical workload on working memory performance

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Many workers, including soldiers, firefighters, and policemen, perform demanding physical work tasks while carrying heavy equipment. For example, soldiers carry around 30-50kg of military gear and perform prolonged standing and marching, and many other postural and movement tasks. The occupational activities of the workers carrying extra weights are not limited to physical tasks. They also perform various mental tasks along with physical ones – the mental and physical tasks are conducted close in time and often simultaneously. For example, in the case of soldiers, the mental tasks include comprehending dynamic battlefield situations, communicating information, making decisions, issuing and receiving operational orders, etc.

In a similar context, workers in the medical field such as doctors, nurses, and pharmacists frequently multitask and are faced with physical workload in addition to their high level of mental workload. For example, nurses are required to complete physical tasks such as lifting patients for transfer out of

bed and from the floor, while completing mental tasks, all in an urgent and busy work environment.

As mentioned above, many human work tasks consist of a physical component (physical sub-tasks) and a mental component (mental sub-tasks) – rarely are there work tasks that only requires the use of one component. Therefore, workers tend to experience both physical and mental workload while completing their work task.

From the human information processing (HIP) point of view, physical and mental tasks constituting a work activity are thought to be mutually influential rather than independent. Indeed, such mutual relationships have been empirically demonstrated in many previous studies. The previous results on the inter-relationship between the concurrent physical and mental tasks lead to the hypothesis that the body-worn equipment weight or postural loading affects the performance of some of their mental tasks. Understanding how the body-worn equipment weight or postural loading affects the performance of different mental tasks will provide a basis for designing work tasks to maximize safety, performance and worker wellbeing. Despite the significance, however, few studies seem to have examined such relationships.

Therefore, this study aimed to empirically investigate the effects of body-worn equipment weight or postural loading on a worker's performance of basic working memory tasks while the worker is simultaneously performing a certain physical task. To accomplish these objectives, two major studies were conducted.

In study 1, the effects of body-worn equipment weight on the

performance of basic working memory tasks were examined. A backpack was adopted as a representative piece of body-worn equipment as it is widely used among workers, including soldiers and firefighters. Three types of physical tasks were considered in this study. They were flat-surface standing, walking along a predetermined route, and walking along a straight route, which are representative physical tasks performed by various workers including soldiers and firefighters. Also, three types of working memory tasks were considered so as to examine the different sub-components of the working memory system, that is, the visuo-spatial sketchpad, phonological loop and central executive systems. The results of data analyses showed that backpack weight affected working memory task scores differently in regards to the type of working memory task and physical task. Overall, working memory task scores had a tendency to decrease as backpack weight increased.

In study 2, the effects of postural loading on the performance of basic working memory tasks were investigated. In the case of the physical task, a specific posture was held for a predetermined amount of time, and four posture groups were considered, each with a different amount of postural loading. Three types of working memory tasks were considered as in study 1. The data analyses revealed significant effects of postural loading on the scores of the working memory tasks. As postural loading increased, all of the three working memory task scores decreased.

The study findings entail that reducing the body-worn equipment weight or postural loading can positively impact the worker's mental task performance in addition to reducing the worker's bodily stresses and the risks of work-related musculoskeletal disorders. This is especially important for situations where workers perform critical mental tasks along with demanding physical tasks, as in the work activities of soldiers, firefighters, pilots and medical team. Such results may contribute to the practical design of products or systems which require multitasking, by providing an experimental basis about the increased mental performance when using such products (or reducing the decrease of mental performance). Such results also provide empirical evidence about possible improvements for work tasks where multitasking of physical and mental tasks occur; this may be in the form of work station design or working posture improvement.

Keywords: backpack weight, postural loading, multitasking, mental task performance, working memory

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Chapter 1. Introduction

1.1 Research background

Many human work tasks consist of a physical component (physical sub-tasks) and a mental component (mental sub-tasks) (Barker and Nussbaum 2011; DiDomenico and Nussbaum 2011; Page 2004; Perry et al. 2008) – rarely are there work tasks that only requires the use of one component. Therefore, workers tend to experience both physical and mental workload while completing their work task. Also, there are many work tasks that have both demanding physical and mental components of the task. For example, health care workers such as nurses are required to complete physical tasks such as lifting patients for transfer out of bed and from the floor, while completing mental tasks, all in an urgent and busy work environment.

From the human information processing (HIP) point of view, physical and mental tasks constituting a work activity are thought to be mutually influential rather than independent. Indeed, such mutual relationships have been empirically demonstrated in many previous studies: multiple studies demonstrated the effects of physical workload on mental task performance (Barker and Nussbaum 2011; Basahel, Young, and Ajovalasit 2010; Brisswalter, Durand, and Delignieres 1995; Chmura, Nazar, and Kaciuba-Uscilko 1994; DiDomenico and Nussbaum 2011; Kerr, Condon, and McDonald 1985; Lorist et al. 2002; Perry et al. 2008; Pontifex et al. 2009;

Reilly and Smith 1986; Sibley and Beilock 2007; Tomporowski 2003). Several studies have demonstrated the effect of mental workload on physical task performance (Andersson et al. 2002; Dault, Frank, and Allard 2001; Kerr, Condon, and McDonald 1985; Maylor, Allison, and Wing 2001; Mehta and Agnew 2012; Shumway-Cook and Woollacott 2000). These empirical findings suggest that the two components are mutually influential in many cases.

Understanding the correlation between the physical and mental components of work task, along with applying these ideas to work task design, is important to the improvement of worker's work performance, in addition to physical and mental well-being. Additionally, understanding such a phenomenon may aid in the design of a safe system that may prevent the loss of lives and property damage. For example, the possible relationship between physical and mental components of a task has been steadily stated in regards to the medical field – it is thought that excessive physical workload may contribute not only to the increase in risks of musculoskeletal diseases, but also has a negative effect on mental task performance, resulting in medication errors or medical accidents (Carayon and Gürses 2005; Gander, Merry, and Miller 2000; Gawande et al. 2003; Krueger 1994; Lewittes and Marshall 1989; Pasupathy and Barker 2012).

In spite of the importance of the abovementioned knowledge, in addition to mentions from previous works, the correlation between the physical and mental components of work tasks is still not well known. Therefore, further studies are required to address the knowledge gaps. One such knowledge gap that needs to be addressed is the effect of body-worn equipment weight or postural loading on mental task performance.

The previous results on the inter-relationship between the concurrent physical and mental tasks lead to the hypothesis that the body-worn equipment weight or postural loading affects the performance of some of their mental tasks. Understanding how the equipment weight or postural loading affects the performance of different mental tasks will provide a basis for designing equipment and work tasks to maximize safety, performance and worker wellbeing. Despite the significance, however, few studies seem to have examined such relationships.

1.2 Research objectives

This study empirically investigated the effect of body-worn equipment weight or postural loading on mental task performance. In particular, working memory retention tasks were selected as mental tasks in this study. Working memory is defined as the temporary, attention-demanding storage that retains new information until usage (Wickens et al. 2013). It is also defined as the brain system that provides temporary storage and manipulation of the information necessary for complex cognitive tasks (Baddeley and Hitch 1974). In human information processing, working memory plays a central role in conducting complicated cognitive tasks (Wickens et al. 2013), and is related to the occurrences of different types of human errors (Norman 1981; Reason 1990; Wickens et al. 2013). Therefore, the findings of this study would be applicable to a wide variety of situations and design problems. According to the Baddeley model (Baddeley 1983), working memory consists of three subcomponents (visuo-spatial sketchpad, phonological loop and central executive systems), each responsible for different functions. For each subcomponent of working memory, the effects of body-worn equipment weight and postural loading were examined.

Accordingly, the objectives of this research were:

- to examine the effects of body-worn equipment weight on the performance of basic working memory tasks, and
- to examine the effects of postural loading on the performance of

basic working memory tasks.

1.3 Dissertation outline

This dissertation consists of two major studies in relation to the research objectives presented in Chapter 1.2. In study 1, the effects of body-worn equipment weight on the performance of basic working memory tasks were examined. In study 2, the effects of postural loading on the performance of basic working memory tasks were examined. The overall structure of this dissertation takes the form of five chapters (Figure 1.1). Brief descriptions of the chapters are presented below.

In Chapter 1, research background and purposes of the study were described. The overall structure of this study is also presented.

In Chapter 2, previous studies on the relationship between physical components and mental components of work task were reviewed. The definition of working memory and its importance were also presented.

In Chapter 3, the effects of body-worn equipment weight on the performance of basic working memory tasks were investigated. Three types of physical tasks (standing, navigating and walking) were considered in this study. They are representative physical tasks performed by various workers including soldiers, firefighters and policemen.

In Chapter 4, the effects of postural loading on the performance of basic working memory tasks were examined. Especially, industrial working postures with a large postural loading variation were chosen.

Finally, a brief summary and implications of the study were presented in Chapter 5. Some limitations of this study were also described along with future research ideas.

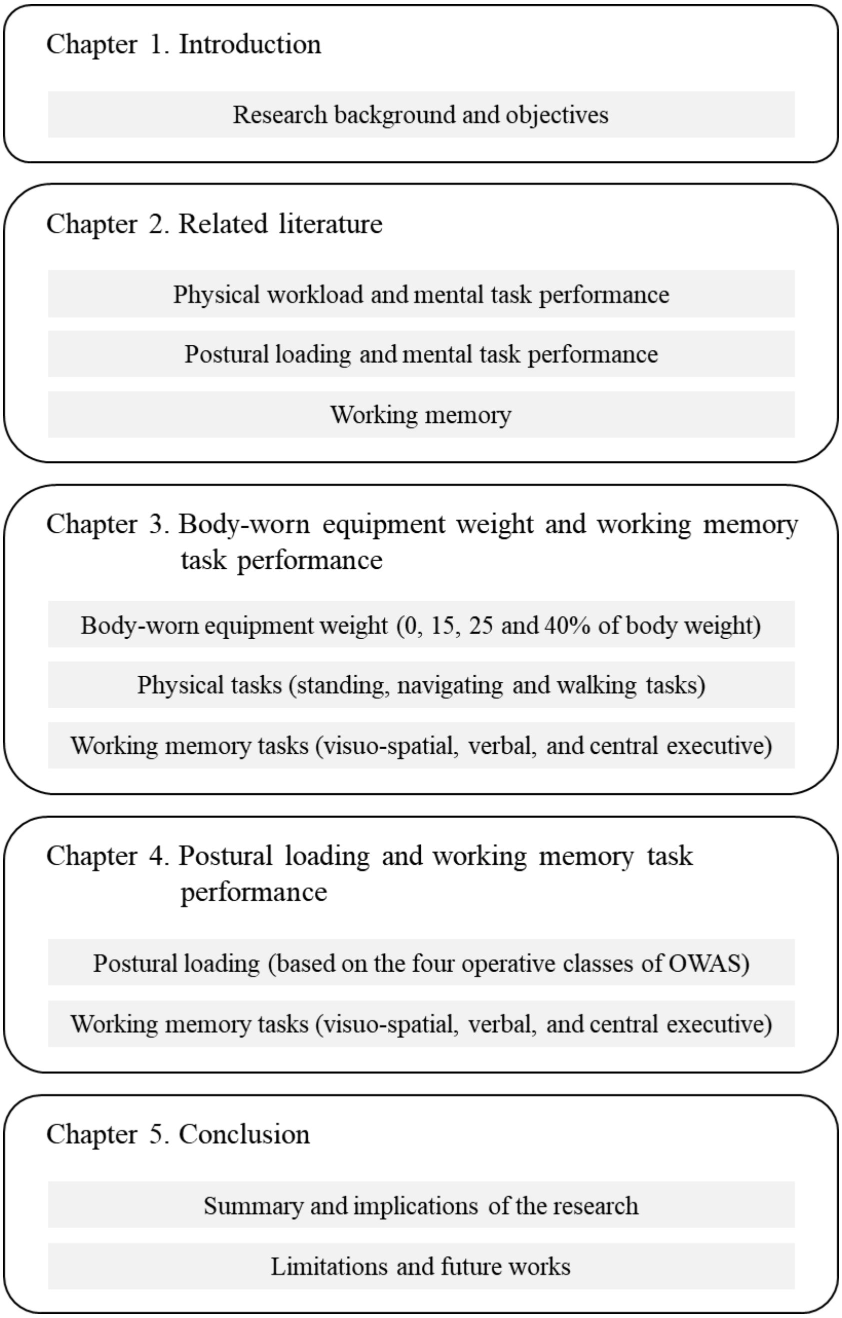


Figure 1.1 The overall structure of the dissertation

Chapter 2. Related literature

2.1 Physical workload and mental task performance

Multiple studies demonstrated that moderate levels of aerobic exercises (cycling and treadmill walking) increased the performance of concurrent mental tasks, such as arithmetic or choice reaction time tasks (Basahel, Young, and Ajovalasit 2010; Brisswalter, Durand, and Delignieres 1995; Chmura, Nazar, and Kaciuba-Uscilko 1994; Reilly and Smith 1986; Tomporowski 2003). Some studies have found that various types of physical exertion (elbow flexion, knee extension, and fatiguing muscle contraction) adversely affected the performance of mental tasks, such as arithmetic and choice reaction time tasks (DiDomenico and Nussbaum 2011; Lorist et al. 2002). Some other studies demonstrated that physical workload and fatigue occurring during occupational activities such as helicopter loading and simulated nursing can decrease the mental task performance (Barker and Nussbaum, 2011; Perry et al., 2008).

A few studies have shown that aerobic exercises increased the performance of working memory tasks (Pontifex et al. 2009; Sibley and Beilock 2007). Pontifex et al. (2009) utilized the Sternberg task as a memory task, and measured reaction time and accuracy of working memory. Sibley and Beilock (2007) utilized a working memory task related to operation and reading spans.

To summarize the literature stated above, numerous studies that analyzed the effects of physical workload generally tested aerobic exercises such as treadmill walking and their cognitive arousal effect. Few empirical studies have been found on the effects of physical workload due to the body-worn equipment weight. Also, few studies have been conducted considering the representative physical tasks performed by soldiers or firefighters, such as walking along a predetermined route. In regards to mental task performance, many studies dealt with complex mental tasks that require multiple cognitive elements.

2.2 Postural loading and mental task performance

Previous works examined the effect of postural balance maintenance or different postures on the performance of mental tasks that require multiple cognitive elements (Dault, Frank, and Allard 2001; Deaton and Hitchcock 1991; Drury et al. 2008; Kerr, Condon, and McDonald 1985; Liao and Drury 2000; Thomas et al. 1991; Yardley et al. 2001). Drury et al. (2008) examined the effect of various postures on security screening task performance. In this study, the working postures were sitting on a high chair, sitting at a desk, and standing, and there was no significant difference in mental task performance in regards to working posture. Dault, Frank, and Allard (2001) observed the effect of postural control on working memory performance. In this study, postural control consisted of standing in a shoulder width stance, tandem stance, and sitting; three types of working memory (visuo-spatial, verbal and central executive) was considered. There was no significant difference in working memory performance according to the type of postural control. Yardley et al. (2001) examined the effect of postural control on auditory discrimination task performance, specifically accuracy and reaction time. Postural control in this study consisted of the standing task on either a stable or moving platform, or sitting task. The results of the study showed that postural balance maintenance had an effect on mental task performance, as performance decreased as postural control became more difficult.

To summarize, most related research either dealt with a small number of postures in a specific work environment or focused on postural control in relationship to balance maintenance. In regards to mental performance, many studies dealt with mental tasks that require multiple cognitive elements; very few studies dealt with specific cognitive elements such as visuo-spatial sketchpad, phonological loop and central executive working memory.

2.3 Working memory

This study investigated the effect of body-worn equipment weight or postural loading on mental task performance, focusing exclusively on the performance of working memory tasks. Working memory (WM) is defined as the temporary, attention-demanding storage that retains new information until usage (Wickens et al. 2013), and it is also defined as the brain system that provides temporary storage and manipulation of the information necessary for complex cognitive tasks (Baddeley and Hitch 1974). WM acts as a basic element in completing various and complicated cognitive tasks. The human information processing model (Wickens et al. 2013) describes the overall process of task completion from recognizing new information or stimulation to making decisions and reacting to the new stimuli. Here, WM not only is required in cognitive operations such as rehearsal, reasoning, and image transformation, but also partakes in perceptual processing such as bottom-up and top-down processing. Therefore, it can be stated that WM plays an important role in human information processing.

According to the information processing context for representing human error, which explains the category of human error in relation to human information processing model by Rasmussen (1983), human error is usually caused by slips, rule-based mistakes, knowledge-based mistakes, lapses, and mode errors, of which the latter three are related directly with WM (Norman 1981; Reason 1990; Wickens et al. 2013). That is, WM can be assumed to be an important factor in human error since it is related to the occurrences of various types of human errors.

According to the Baddeley model (Baddeley 1983), WM consists of three subcomponents (visuo-spatial sketchpad, phonological loop, and central executive systems), each responsible for different functions. The visuo-spatial sketchpad holds and processes visual and spatial images; the phonological loop maintains auditory memory through internal recitation; the central executive systems monitors and manipulates both of the two WM buffers. Thus, it can be inferred that the subcomponents of WM take part in various types of mental tasks that require different functions. Understanding the elements of WM that form the basis of human information processing may contribute greatly to understanding the complex cognitive tasks that may consist of various cognitive elements.

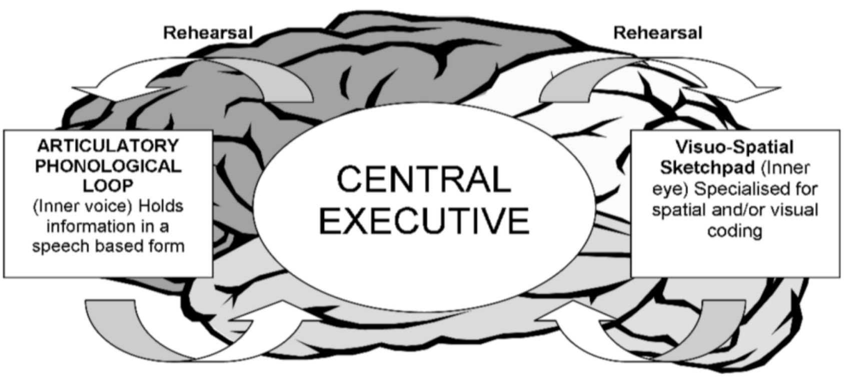


Figure 2.1 Working memory model (Baddeley 1983)

Chapter 3. Body-worn equipment weight and working memory task performance

3.1 Background

Many workers, including soldiers, firefighters, and policemen, perform demanding physical work tasks while carrying heavy equipment. Soldiers carry around 30-50kg of military gear and perform prolonged standing, marching, and many other postural and movement tasks (Brady, Lush, and Chapman 2011; Dean 2008; Drain et al. 2012; van Dijk 2009). Firefighters carry anywhere around 20-40kg or more of equipment, which includes breathing apparatus, bunker gear, and helmet (Boorady et al. 2013; Griefahn, Künemund, and Bröde 2003; Kang and Kim 2008; Son, Lee, and Tochihara 2013). Policemen carry around 10kg of various protective and functional equipment such as duty belt and body armour (Dempsey, Handcock, and Rehrer 2013; Hooper 1999; Stubbs et al. 2008). These extra weights represent significant physical loadings on the musculoskeletal system and can cause bodily discomfort and pain, increase the risks of work-related musculoskeletal disorders and compromise physical work performance. Multiple research studies have investigated ways to reduce equipment weight in an effort to address these negative consequences (Attwells et al. 2006; Beekley et al. 2007; Harman et al. 1999; Holewun and Lotens 1992; Knapik, Reynolds, and Harman 2004).

The occupational activities of the workers carrying extra weights are not limited to physical tasks. They also perform various mental tasks along with physical ones – the mental and physical tasks are conducted close in time and often simultaneously. For example, in the case of soldiers, the mental tasks include comprehending dynamic battlefield situations, communicating information, making decisions, issuing and receiving operational orders, etc. These mental tasks are mission-critical; and, performance deterioration and human errors can incur significant costs. Similarly, firefighters and policemen conduct critical mental tasks under time pressure, along with demanding physical tasks.

The previous results on the inter-relationship between concurrent physical and mental tasks mentioned in Chapter 1.1 lead to the hypothesis that the weight of the body-worn equipment carried by soldiers, firefighters, policemen, etc., affects the performance of some of their mental tasks. Understanding how the equipment weight affects the performance of different mental tasks will provide a basis for designing equipment and work tasks to maximize safety, performance and worker wellbeing of those who use such equipment. Despite the significance, however, few studies seem to have examined such relationships as mentioned in Chapter 2.1. Previous studies on the topic of backpack weight mostly dealt with physical performance or discomfort. Also, few studies have been conducted considering the representative physical tasks frequently performed by soldiers or firefighters, such as flat-surface standing and walking along a predetermined route.

3.2 Overview

This chapter aimed to empirically investigate the effects of body-worn equipment weight on a worker's performance of basic WM tasks while simultaneously performing a certain physical task.

A backpack was adopted as a representative piece of body-worn equipment as it is widely used among workers, including soldiers and firefighters. The external weight imposed on the body was set at four levels relative to the participants' body weight.

The physical task consisted of flat-surface standing, walking along a predetermined route and walking along a straight path, which are representative physical tasks performed by various workers including soldiers and firefighters. The three physical tasks were named as the standing, navigating, and walking tasks, respectively. The current study examined the backpack weight effects on WM task performance for each of the three physical tasks, separately.

Accordingly, the purposes of this chapter were:

- to examine the effects of backpack weight on a worker's performance of basic WM tasks while simultaneously performing the standing task with loaded backpack,
- to examine the effects of backpack weight on a worker's

performance of basic WM tasks while simultaneously performing the navigating task with loaded backpack,

- to examine the effects of backpack weight on a worker's performance of basic WM tasks while simultaneously performing the walking task with loaded backpack, and
- to examine whether the effects of backpack weight on a worker's performance of basic WM tasks depend on the types of physical tasks.
    - Two-way repeated measures ANOVA was conducted to test the effect of backpack weight and physical task type on WM task performance.

Three types of WM tasks (visuo-spatial component, phonological loop and central executive systems) were considered based on Baddeley's WM model (Baddeley 1983). Other variables (behavioural, physiological, and psychophysical measures) that would be helpful in understanding the effects of backpack weight on WM task performance were also considered.

3.3 Standing task

3.3.1 Method

3.3.1.1 Participants

Thirty participants (15 males and 15 females) in their 20s and 30s participated in the experiment. Participants were free of musculoskeletal and neurological disorders. All participants signed an informed consent form prior to participation. The data collection protocol had been approved by the Institutional Review Board of Seoul National University. The participants' age, height and weight are summarized in Table 3.1.

Table 3.1 Characteristics of participants

	Male (n=15) **Mean (SD)**	**Female (n=15)** **Mean (SD)**	**Total (n=30)** **Mean (SD)**
Age (years)	28.1 (3.5)	26.1 (2.5)	27.1 (3.1)
Height (cm)	176.6 (5.9)	164.5 (4.3)	170.8 (8.0)
Weight (kg)	74.9 (14.4)	55.0 (5.2)	64.9 (14.7)

3.3.1.2 Experimental tasks

In this experiment, the participants conducted three experiment tasks each of which consisted of a physical and a WM task simultaneously performed.

The physical task was quiet standing with loaded backpack and was common to all three experiment tasks. Backpack weight was the independent variable of the study and had four levels in relation to the body weight (0, 15, 25 and 40% of body weight, denoted as BW 0, BW 15, BW 25, and BW 40, respectively). The four backpack weight levels for each participant were generated by placing different combinations of weight plates (1, 1.5, 3, 5, and 10kg weights) into a backpack. The participant stood on top of a Bertec force plate (model 4060, Bertec Corporation, Columbus, USA), in balance, for 15 seconds. Participants were instructed to complete this task in a comfortable stance, and with both feet fixed on the force plate.

Different WM tasks were adopted for the three experiment tasks. They were the Corsi block task (Corsi 1972), digit span task (Wechsler 1939), and 3-back task (Kirchner 1958). They corresponded to the three components of the Baddeley's WM model (the visuo-spatial sketchpad, phonological loop and central executive systems).

The Corsi block task (Corsi 1972) with five stimuli was used as the visuo-spatial WM task. A sequence of five black circles flashed one by one on a screen, with each circle located within one of the twelve predetermined square frames. The participants were instructed to memorize the locations and time order of the five stimuli and recall them after a short time period (15 seconds in this study). For each stimulus, earning a full point required correctly recalling both the spatial and temporal position of the stimulus. For each task trial, the range of possible scores was 0 to 5. Figure 3.1 provides an example Corsi block task trial – note that the numbers 1-5 in the black circles representing the order of the presentation of the five stimuli were not provided in the actual experiment trials. The locations of the twelve square frames changed randomly across trials. The Corsi block task is known to evaluate spatial and visual components of WM, and has been widely used in various studies (De Renzi and Nichelli 1975; Della Sala et al. 1999; Joyce and Robbins 1991; Rowe, Hasher, and Turcotte 2008; Smyth and Scholey 1994; Vilkki and Holst 1989).

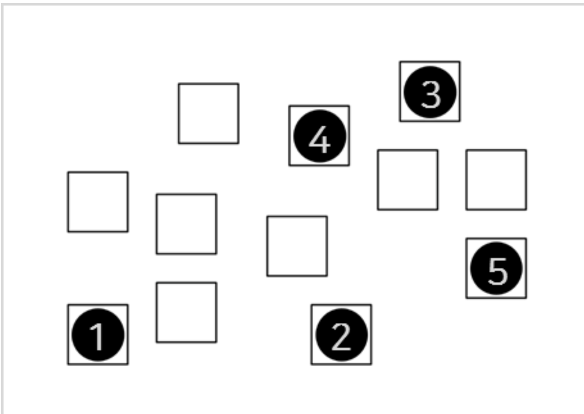


Figure 3.1 An example Corsi block task trial

The digit span task was employed as the phonological loop WM task

(Wechsler 1939). In each task trial, 10 single digit numbers were auditorily presented to the participants, and, after a short time period (15 seconds in this study), the participants were instructed to repeat the numbers back in the same order. For each task trial, the range of possible scores was 0 to 10. The digit span task is a serial recall task for evaluating temporary retention of verbal material (Conrad 1964; Henson 1996) and has been widely used in past research (Conti-Ramsden 2003; Hick, Botting, and Conti-Ramsden 2005; Orsini et al. 1987; Owen et al. 2010).

The 3-back task (N-back task with N=3) (Kirchner 1958) was utilized as the central executive WM task. In each task, each participant was auditorily presented a sequence of stimuli (single-digit numbers). The task consisted of answering with the number presented three numbers earlier if the current number matches a pre-defined target number. Each number sequence consisted of 16 numbers and contained four target numbers at random positions. The range of possible scores was 0 to 4. The N-back task is considered a useful tool in evaluating the central executive WM, as it taps into many aspects of the central executive's manipulation of WM, including online storage of recent information, selective attention, remembering task demands, and updating and reorganizing stored items (Gluck, Mercado, and Myers 2013).

The three experiment tasks, each of which required simultaneously performing the quiet standing task and one of the WM tasks, were named as the V-S (visuo-spatial WM task and standing), P-S (phonological loop WM task and standing) and C-S (central executive WM task and standing) tasks, respectively.

3.3.1.3 Procedures and dependent measures

In this study, each participant performed 12 experiment trials (12 = 4 backpack weight levels × 3 experiment tasks). The order of the 12 trials was randomized for each participant. To minimize the effect of fatigue, each participant conducted the 12 trials over a period of two days and plenty of time for rest (minimum of 30 minutes) was given between trials. The minimum rest time of 30 minutes was determined based on existing research on muscle fatigue and recovery (Barbonis 1978; Jones and Ruiter 2006; Miller et al. 1987; Milner, Corlett, and O'Brien 1986). Prior to the experiment trials, an introduction/training session had been provided to the participants to allow for familiarization with the experimental tasks.

The procedure for the V-S task was as follows: at the beginning of a task trial, the participant stood on the force plate without a backpack. Then, the participant was presented with the sequence of black circles for the Corsi block task. A monitor screen (27 inches) placed in front of the participant was used to display the sequence. At the completion of the visuo-spatial information presentation, two experimenters standing by on either side of the participant put the backpack on his/her back – this allowed the participant to focus entirely on the experiment task without the distraction of having to don the backpack by himself/herself. Note that the participant was given the backpack to wear in all conditions, including the condition with no external weight to bear. The participant performed standing for 15 seconds while trying to retain the visuo-spatial information. The 15 seconds time duration for standing (and, thus, the time duration during which the participant tried to retain the visual information) was based on the knowledge that short-term memory holding time is generally known as 10-15 seconds (Campbell and Bagshaw 2008; Goldstein 2014). Immediately after the 15 seconds time interval, the participant took off the backpack with the assistance from the two experimenters and reproduced the sequence of black circles by pointing on the answer sheet presented on the monitor screen. The Corsi block task score was recorded.

The procedure for the P-S task was as follows: at the beginning of a task trial, the participant stood on the force plate without a backpack. Then, the participant was presented with auditory stimuli (ten numbers) according to the protocol of the digit span task. At the completion of the auditory information presentation, the experimenters put the backpack on the participant’s back similarly to the V-S task. The participant performed standing for 15 seconds while trying to retain the auditory information. Immediately after the 15 seconds time interval, the participant took off the backpack again with the assistance from the two experimenters and reproduced the auditory stimuli by speaking. The digit span task score was recorded.

The procedure for the C-S task was as follows: at the beginning of a trial, the participant stood on the force plate without a backpack, as in the other two tasks, and, received the target number for the 3-back task; the experimenters put the backpack on the participant’s back. Then, the participant performed the standing and 3-back tasks simultaneously. The participant was instructed to verbally respond immediately when the target number was presented. The 3-back task score was recorded.

For all three experiment tasks, behavioural, physiological, and psychophysical response data, which were thought to be helpful in understanding the effects of backpack weight on WM task performance, were collected from the participants during or after each task trial. Postural sway data were obtained using the force plate recordings of the centre of pressure (CoP) position-time profile during the 15 seconds of the standing task. The sampling frequency of the force plate was 100Hz. The postural sway data did not include the measurements during the process of putting on and taking off the backpack. Among various postural sway measures, sway area, sway path and sway variance were employed in this study as they had been widely utilized in research studies (Albright and Woodhull-Smith 2009; Diener et al. 1984; Kerr, Condon, and McDonald 1985; Maylor, Allison, and Wing 2001; Panjan and Sarabon 2010; Rode, Tiliket, and Boisson 1997; Shumway-Cook and Woollacott 2000; Thapa et al. 1996). The three posture sway measures are described in Table 3.2. Sway area was calculated using the area of convex hull which is defined as the smallest polygon in which no internal angle exceeds 180 degrees and contains all sites of occurrence. The vertices of convex hull polygon were computed using the gift wrapping algorithm (Wollseifen 2011). For the sway variance, the medio-lateral (ML) and anterior-posterior (AP) directions were considered.

Table 3.2 Postural sway measures

Measure	Unit	Description
Sway area	mm^2	The time integral of the area swept by the CoP trajectory with respect to platform center
Sway path	mm	The length of the trajectory of the CoP sway
Sway variance	mm^2	The variance of the sway amplitude (ML/AP)

Heart rate was measured right after each task trial using Samsung gear fit 2 – heart rate is generally considered a sensitive measure of both physical and mental workloads and also stresses (Coles and Sirevaag 1987; Drury, Goonetilleke, and Maurice 1989; Kalsbeek 1971; Sharit and Salvendy 1982). Additionally, each participant conducted subjective ratings of physical discomfort and mental workload immediately after each task trial. The Borg CR10 scale (Borg 1982) was employed.

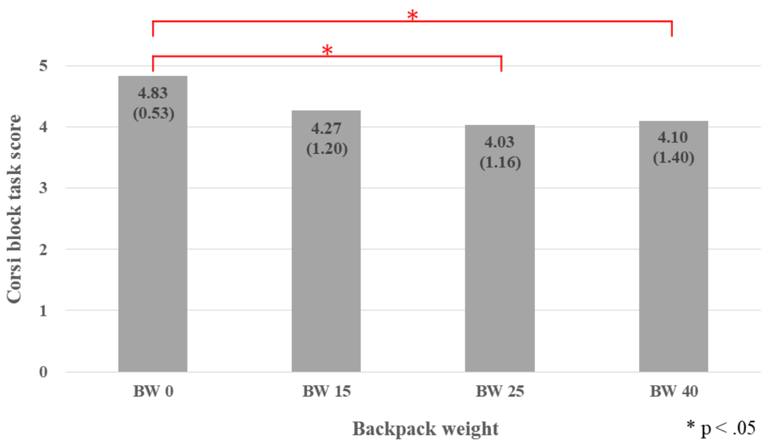
3.3.1.4 Data analyses

For each of the three experiment tasks, one-way repeated measures ANOVA was conducted to test the effect of backpack weight on the corresponding WM task score and other dependent measures (behavioural, physiological, and psychophysical measures). Mauchly's test was performed to assess the sphericity of data for each ANOVA. In cases where sphericity was violated, the degrees of freedom were corrected – the Greenhouse-Geisser correction was used when the Greenhouse-Geisser estimate of sphericity (ε) was less than 0.75; otherwise, the Huynh-Feldt correction was used (Field 2009). In the case of significant ANOVA results, post-hoc Bonferroni multiple pairwise comparisons were conducted. Bonferroni corrections were made. All statistical tests were conducted using IBM SPSS Statistics 23.0, and were based on an alpha level of 0.05.

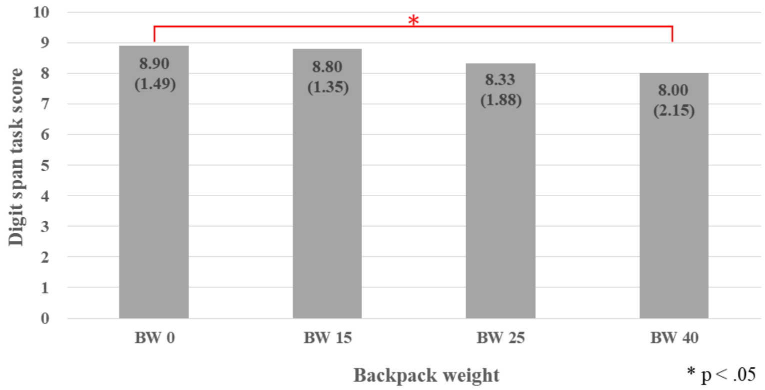
3.3.2 Results

3.3.2.1 Working memory task scores

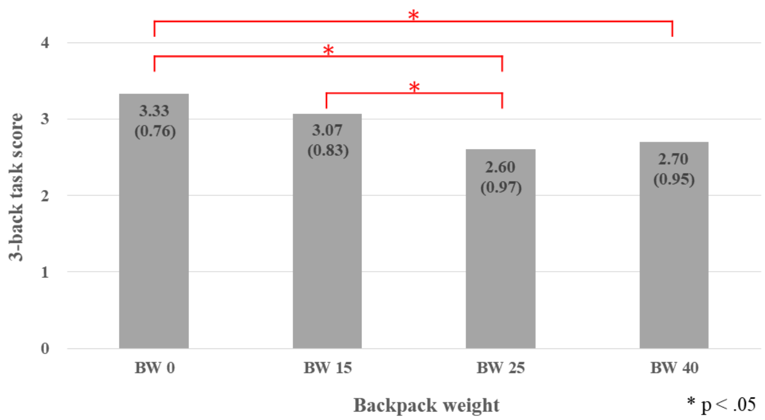
The ANOVAs revealed that backpack weight significantly affected all of the three WM task scores (F=4.401, 3.703 and 11.723 for the V-S, P-S and C-S tasks, respectively, p<.05). For all of the three experiment tasks (the V-S, P-S and C-S tasks), WM task performance decreased as backpack weight increased. The effect of backpack weight on WM task performance was more pronounced for the V-S and C-S tasks than the P-S task. Figure 3.2 visually depicts the backpack weight effects. In each figure, the mean and standard deviation of the WM task scores are presented for each level of backpack weight. The asterisks indicate statistically significant differences detected by the post-hoc Bonferroni multiple pairwise comparisons.



(a) V-S task



(b) P-S task

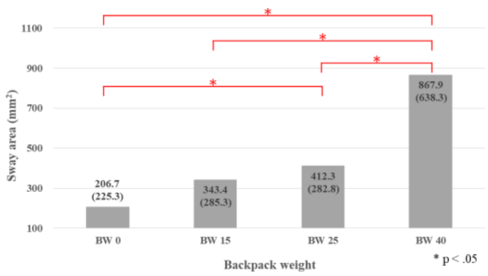


(c) C-S task

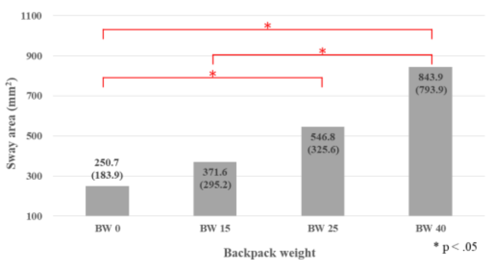
Figure 3.2 Effects of backpack weight on WM task scores

3.3.2.2 Postural sway measures

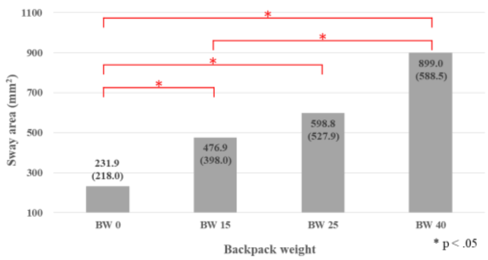
The ANOVAs indicated that backpack weight significantly affected all three postural sway measures for each of the three experiment tasks (F=19.373, 11.210 and 12.404 for the V-S, P-S and C-S tasks, respectively, p<.05). As backpack weight increased, all of the three postural sway measures increased. Figures 3.3-3.5 visually depict the effects of backpack weight on the three postural sway measures (sway area, sway path, and sway variance), respectively. For the sway variance measure, observations in regards to the medio-lateral (ML) and anterior-posterior (AP) directions were presented.



(a) V-S task

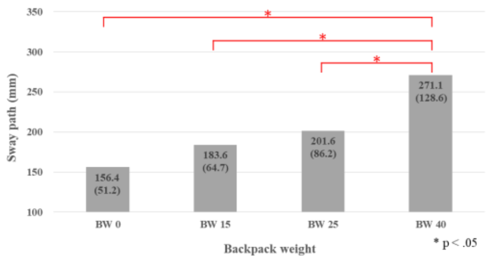


(b) P-S task

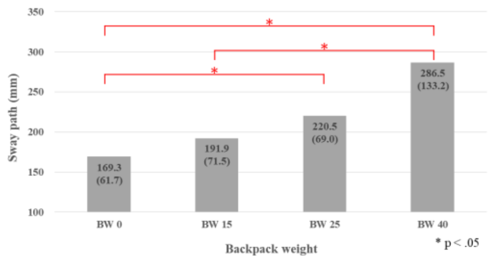


(c) C-S task

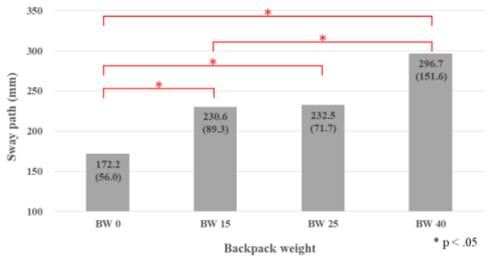
Figure 3.3 Effects of backpack weight on sway area



(a) V-S task

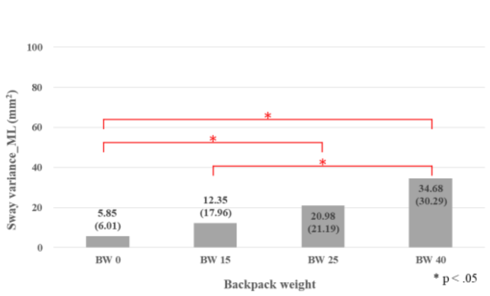


(b) P-S task

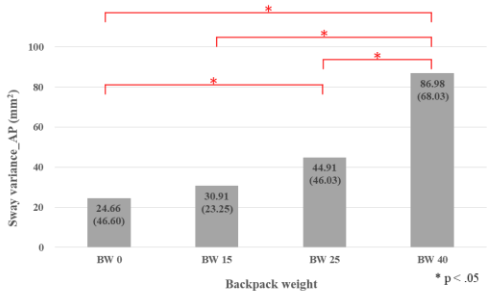


(c) C-S task

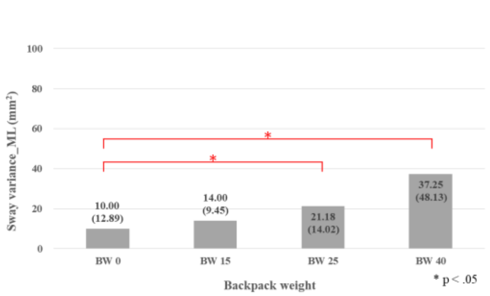
Figure 3.4 Effects of backpack weight on sway path



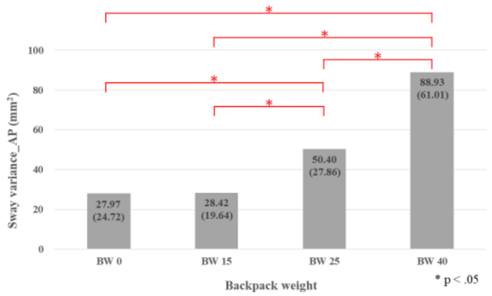
(a) V-S task (ML)



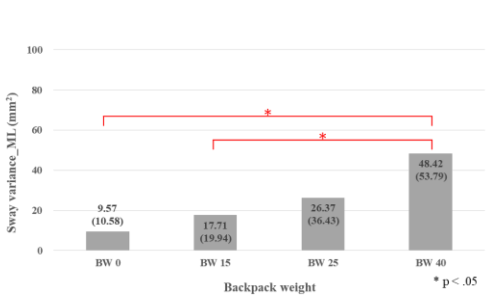
(b) V-S task (AP)



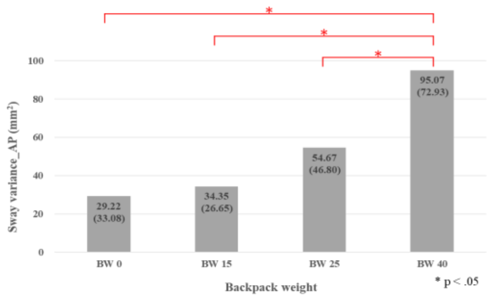
(c) P-S task (ML)



(d) P-S task (AP)



(e) C-S task (ML)



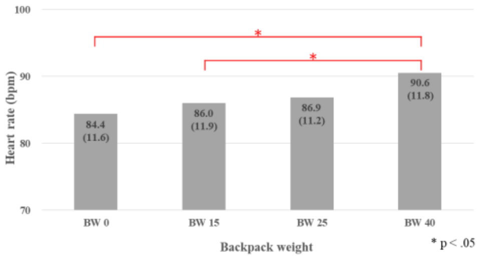
(f) C-S task (AP)

Figure 3.5 Effects of backpack weight on sway variance

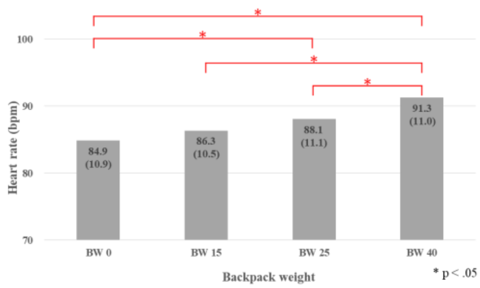
*** note: medio-lateral direction (ML), anterior-posterior direction (AP)**

3.3.2.3 Heart rate

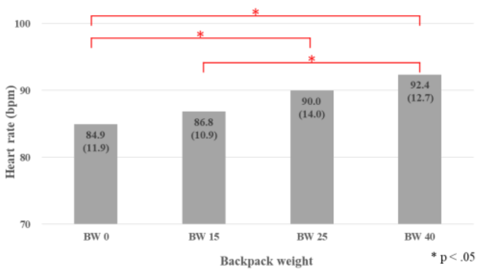
The ANOVA found that backpack weight significantly affected heart rate in all three experiment tasks (F=10.057, 20.621 and 17.326 for the V-S, P-S and C-S tasks, respectively, p<.05). As backpack weight increased, heart rate increased for all of the three experiment tasks. Figures 3.6a-3.6c visually depict the backpack weight effects.



(a) V-S task



(b) P-S task

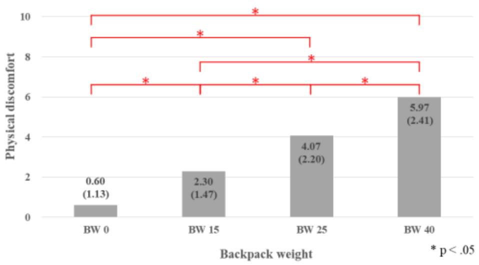


(c) C-S task

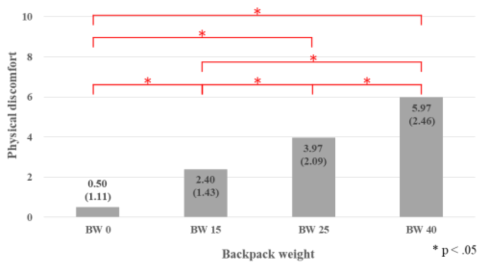
Figure 3.6 Effects of backpack weight on heart rate

3.3.2.4 Physical discomfort and mental workload

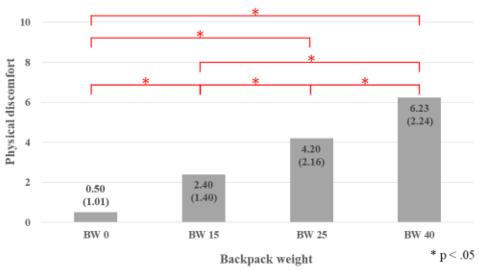
The ANOVA results indicated that backpack weight significantly affected both the physical discomfort and mental workload ratings for all three experimental tasks (F=97.599, 87.611 and 106.020 for the V-S, P-S and C-S tasks, respectively, p<.05). As backpack weight increased, physical discomfort and mental workload ratings increased for all of the three experiment tasks. Figures 3.7-3.8 visually depict the effects of backpack weight.



(a) V-S task

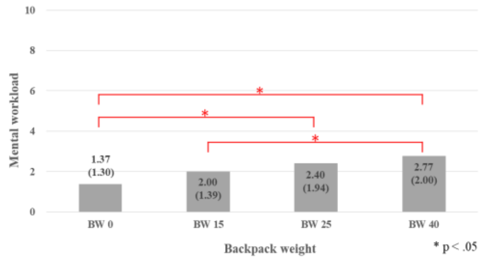


(b) P-S task

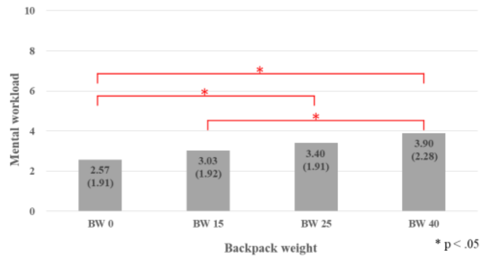


(c) C-S task

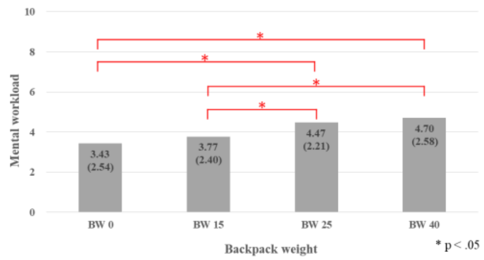
Figure 3.7 Effects of backpack weight on physical discomfort



(a) V-S task



(b) P-S task



(c) C-S task

Figure 3.8 Effects of backpack weight on mental workload

3.3.3 Discussion

The objective of the current study was to empirically investigate the effects of backpack weight (body-worn equipment weight) on a worker's performance of basic WM tasks while the worker is simultaneously performing flat-surface standing with loaded backpack. Backpack weight had four levels (0, 15, 25, and 40% of the worker's body weight). Three WM tasks, that is, the Corsi block, digit span and 3-back tasks, were considered so as to examine the different sub-components of the WM system, that is, the visuo-spatial sketchpad, phonological loop and central executive systems. The scores of the three WM tasks and a set of measures pertinent to postural sway, heart rate, physical discomfort and perceived mental workload were employed as the dependent variables of the study. Statistical analyses were conducted to test the effects of backpack weight on the dependent variables.

The data analyses revealed significant effects of backpack weight on the scores of the WM tasks and also the other dependent variables. For all of the three experiment tasks (the V-S, P-S and C-S tasks), WM task performance decreased as backpack weight increased (Figure 3.2). Also, as backpack weight increased, all of the three postural sway measures, and the heart rate, physical discomfort rating, and mental workload rating increased (Figures 3.3-3.8).

The observed backpack weight effects on WM task performance (Figure

3.2), that is, decreases in WM task performance resulting from increased backpack weight, could be explained largely in terms of the limited attentional resources of the human information processing system.

A human operator has a limited capacity of attention resources (Broadbent 2013; Kahneman 1973; Pashler and Sutherland 1998; Treisman 1960; Wickens et al. 2013) and when having to perform multiple tasks concurrently, he/she must divide attention or allocate attentional resources between these different tasks (Gopher 1993; Kahneman 1973; Wickens et al. 2013). If the total attention demand of the concurrent tasks exceeds the human capacity, the performance of one or more of these tasks will suffer (Wickens et al. 2013). In this study, each experiment trial required the participants to simultaneously perform a flat-surface standing task (with loaded backpack) and a WM task. The standing task required body balance maintenance, which is accomplished through feedback (compensatory reactive postural responses) and feedforward control (anticipatory postural control) (Shumway-Cook and Woollacott 2007). Such postural control requires attentional resources (Kerr, Condon, and McDonald 1985; Lajoie et al. 1993, 1996; Shumway-Cook et al. 1997; Teasdale et al. 1993). Also, each of the three WM tasks employed in this study demands attentional resources as it requires the participants to perceive information in the environment and maintain it through rehearsal (Wickens et al. 2013). It is thought that in each of the three experiment tasks, increased backpack weight increased the difficulty of the standing task, and, therefore, increased the amount of attention allocated to it, and this further resulted in the shortage of available resources for the concurrent WM task and eventually its performance decrease. The increases in the three postural sway measures associated with increased backpack weight, shown in Figures 3.3-3.5, seem to depict the impact of backpack weight on the difficulty of the standing task. Also, the increases in perceived mental workload associated with increased backpack weight, shown in Figure 3.8, are thought to reflect the progressive reduction of attentional resources available for the WM tasks resulting from backpack weight increases.

The observed backpack weight effects on the performance of the WM tasks (Figure 3.2) could also be explained on the basis of the neural mechanisms underlying different physical and mental tasks. From the neuroscience point of view, two tasks performed simultaneously are considered interfering with each other when their individual patterns of brain activation have a significant overlap, in other words, when they utilize the very same population of neurons (Klingberg and Roland 1997; Klingberg 1998; Passingham 1996; Rémy et al. 2010; Roland and Zilles 1998; Wu, Kansaku, and Hallett 2004). This neuroscience view on between-task interference is similar to the idea that concurrent tasks interfere with one another when they compete for limited attentional resources.

The participants in this study conducted three experiment tasks, each of which required simultaneously conducting a standing and a WM task.

According to existing neuroscience studies, standing activates the following brain areas: dorsolateral prefrontal cortex (DLPFC), midline cerebellum (vermal/paravermal cerebellum), posterior parietal cortex, supplementary motor area (SMA), premotor cortex (PMC), occipital area (primary visual cortex), front eye field (FEF) and pons (pontine nuclei) (Chambers and Sprague 1955; Corbetta and Shulman 2002; Courville 1966; Flumerfelt, Otabe, and Courville 1973; Luks et al. 2007; Mihara et al. 2008; Mihara et al. 2012; Ouchi et al. 1999; Wittenberg et al. 2017).

Visuo-spatial WM tasks have been reported to activate the ventrolateral prefrontal cortex (VLPFC), posterior parietal cortex, PMC, occipital area, and anterior cingulate cortex (ACC) (Awh, Jonides, and Smith 1996; Awh and Jonides 1998; Cohen et al. 1997; Courtney et al. 1997; Fiez et al. 1996; Gluck, Mercado, and Myers 2013; Haxby, Grady, and Horwitz 1991; Kammer et al. 1997; Klingberg 1998; Na et al. 2000; Salmon et al. 1996; Ungerleider 1995). Hence, the standing and visuo-spatial WM tasks of the V-S task of the current study have an overlap of brain activation in the posterior parietal cortex, PMC, and occipital area, and, thus, can be thought of as interfering with each other.

Phonological loop WM tasks have been reported to activate the following brain areas: VLPFC, primary auditory cortex, PMC, SMA, Broca’s area, posterior parietal cortex, ACC, and posterior-lateral cerebellum (Awh, Jonides, and Smith 1996; Awh and Jonides 1998; Cohen et al. 1997; Courtney et al. 1997; Fiez et al. 1996; Gluck, Mercado, and Myers 2013; Hertrich, Dietrich, and Ackermann 2016; Kammer et al. 1997; Klingberg 1998; Meister et al. 2007; Na et al. 2000; Paulesu, Frith, and Frackowiak 1993; Salmon et al. 1996; Smith et al. 1998; Watkins and Paus 2004; Wilson and Iacoboni 2006). Thus, the standing and phonological loop WM tasks of the P-S task of the current study can be regarded as interfering with each other as they have an overlap of brain activation in the PMC, posterior parietal cortex, and SMA.

Central executive WM tasks are known to activate the DLPFC, VLPFC, primary auditory cortex, PMC, SMA, posterior parietal cortex, posterior-lateral cerebellum, ACC, and thalamus (Courtney et al. 1997; Gluck, Mercado, and Myers 2013; Henson, Shallice, and Dolan 1999; Jonides et al. 1993; Klingberg 1998; Na et al. 2000; Nyberg, Cabeza, and Tulving 1996; Owen 2000; Owen et al. 2005; Wagner et al. 1998; Wagner et al. 1998). Therefore, the standing and central executive WM tasks of the C-S task of the current study have an overlap of brain activation in the DLPFC, PMC, posterior parietal cortex, and SMA, and, thus, can be thought of as interfering with each other.

As described above, each of the three experiment tasks (the V-S, P-S and C-S tasks) is subject to dual-task interference as the standing and WM tasks constituting it have a significant overlap of neural activation in brain areas. As backpack weight increases, the amount of neuronal resources used by the standing task would increase leading to increased dual task interference and thus decreased WM task performance (Figure 3.2).

The observed effects of backpack weight on WM task performance (Figure 3.2) may also be attributed to the impacts of negative emotional experience on human information processing, especially, the narrowing of attentional scope.

Attentional scope is defined as “the range of cues an organism uses” (Easterbrook 1959), and also “the amount of information one is aware of at a given time” (Burke, Heuer, and Reisberg 1992; Cacioppo and Berntson 1994). Previous research studies have shown that negative emotions, including pain, annoyance and mental fatigue, can reduce an individual’s attentional scope (Christianson and Loftus 1990; Fredrickson and Branigan 2005; Gasper and Clore 2002). In a situation where the attentional scope is reduced, it may be difficult for people to effectively allocate attentional resources to target information (Dale 2014; Olivers and Nieuwenhuis 2006). Additionally, it has been shown that individuals in a narrowed attentional state will be more susceptible to the attentional blink (MacLean and Arnell 2010; MacLean, Arnell, and Busseri 2010; Vermeulen 2010) – attentional blink is a phenomenon in which the second of two consecutive target stimuli cannot be detected or identified when the second one appears close in time to the first (Raymond, Shapiro, and Arnell 1992). Thus, narrowing of attentional scope due to negative emotions would hinder performing WM tasks - relatedly, Wickens et al. (2013) stated that stressors such as anxiety, fatigue, frustration, and anger may degrade WM as they distract or divert attention away from rehearsal of phonetic or spatial material, resulting in the degradation of remembered information. In the current study, perceived physical discomfort was found to increase as backpack weight increased (Figure 3.7). Across the three experiment tasks, the average discomfort rating for the BW 40 condition was about 6 on the 10-point scale indicating severe feelings of discomfort - note that: the ratings of 5 and 7 on the discomfort scale were associated with the verbal anchors “strong” and “very strong,” respectively. Severe feelings of discomfort are considered as pain (de Looze, Kuijt-Evers, and van Dieën 2003; Magnusson, List, and Helkimo 1995; Smith, Andrews, and Wawrow 2006; Zhang, Helander, and Drury 1996). Also, heart rate increased as backpack weight increased indicating an increase in physical and mental workload (Figure 3.6). These changes associated with increased backpack weight may have caused increases in negative emotions, have caused narrowing of attentional scope, and have further disrupted the WM tasks.

The above accounts of the study findings on the basis of the impacts of negative emotional experience are further supported by the neural mechanism of discomfort/pain perception. The process of pain perception is known to activate ACC, primary/secondary somatosensory cortex (S1/S2), anterior insular cortex, thalamus, SMA, posterior parietal cortex, DLPFC, VLPFC, amygdala, periaqueductal grey (PAG), and basal ganglia (Coghill et al. 1994; May 2007; Price 2000; Wiech, Ploner, and Tracey 2008). The ACC becomes active during emotional reaction to pain (May 2007; Wiech, Ploner, and

Tracey 2008). The S1 and S2 are activated during discriminative sensory pain transmission (Coghill et al. 1994; May 2007). The activation of the anterior insular cortex and posterior parietal cortex has been linked with integrating somatosensory nociceptive input with other contextual inputs to provide an overall sense of intrusion and threat to the body (May 2007; Price 2000; Wiech, Ploner, and Tracey 2008). The thalamus and PAG, a core component of the descending pain modulatory system, are activated when the central nervous system (CNS) facilitates or inhibits pain processing at the level of the spinal cord (May 2007; Wiech, Ploner, and Tracey 2008). Activation of the SMA reflects the engagement of motor system in planning or producing a behavioral response to pain (Coghill et al. 1994; May 2007). The DLPFC becomes active when the CNS modulates activation in pain-associated regions, and the VLPFC is activated in association with the modulation of aversive stimuli based on reappraisal (Wiech, Ploner, and Tracey 2008). The amygdala becomes active during emotional and somatic responses to pain (May 2007). The basal ganglia is activated when the CNS processes nociceptive information (May 2007).

The visuo-spatial WM task considered in this study and the pain perception from increased backpack weight have an overlap of brain activation in the ACC, VLPFC, posterior parietal cortex (Gluck, Mercado, and Myers 2013; Klingberg 1998; May 2007; Na et al. 2000; Price 2000; Wiech, Ploner, and Tracey 2008). The Phonological loop WM task and the pain perception have an overlap in the ACC, VLPFC, posterior parietal cortex, and

SMA (Awh, Jonides, and Smith 1996; Gluck, Mercado, and Myers 2013; Hertrich, Dietrich, and Ackermann 2016; Klingberg 1998; May 2007; Na et al. 2000; Paulesu, Frith, and Frackowiak 1993; Smith et al. 1998; Wiech, Ploner, and Tracey 2008). The central executive WM task and the pain perception have an overlap of brain activation in the ACC, VLPFC, DLPFC, posterior parietal cortex, and SMA (Courtney et al. 1997; Gluck, Mercado, and Myers 2013; Henson, Shallice, and Dolan 1999; Jonides et al. 1993; May 2007; Nyberg, Cabeza, and Tulving 1996; Owen 2000; Owen et al. 2005; Smith, Jonides, and Koeppe 1996; Wagner et al. 1998; Wiech, Ploner, and Tracey 2008), and, thus, can be thought of as interfering with each other.

An interesting observation from the current study results was that the effect of backpack weight on WM task performance was more pronounced for the V-S and C-S tasks than the P-S task (Figure 3.2) – the V-S and C-S tasks showed 17% and 22% reductions in the mean WM task score as the backpack weight increased from BW 0 to BW 40; on the other hand, the P-S task showed a moderate 10% reduction associated with the increase in the backpack weight. This phenomenon may be explained by the multiple resource theory (Wickens 1991). According to the multiple resource theory, there are two main processing codes, spatial and verbal. If two tasks require different processing codes, parallel processing with divided attention becomes easier, leading to less dual-task interference (Wickens 1991, 2002). However, if two tasks require the same processing code, the performance of one or more of these tasks can be decreased due to the significant dual-task interference (Wickens 1991). The threaded cognition theory (Salvucci and Taatgen 2008) also explains information processing in terms of within-resource seriality and between-resource parallelism. This theory states that two tasks can be conducted simultaneously when separate resources are used, but in the case when a particular resource is required in both tasks, tasks are conducted serially resulting in the reduction of task performance. The standing task used in this study requires the participant to maintain body balance, and requires the visuo-spatial (especially peripheral vision) and central executive resources (Horak 2006; Manchester et al. 1989; Mihara et al. 2008; Ouchi et al. 1999; Paulus, Straube, and Brandt 1984; Shumway-Cook and Woollacott 2007; Van Iersel et al. 2008). Therefore, conducting the visuo-spatial and central executive WM tasks while simultaneously performing the standing task would require the use of the same resource. Such use of the same resource would result in significant dual-task interference. On the other hand, when the phonological WM task and the standing task are executed at the same time, less dual-task interference is expected as they use different resources, and, therefore, time-sharing efficiency would be improved (Sanders and McCormick 1993; Wickens et al. 2013).

3.4 Navigating task

3.4.1 Method

3.4.1.1 Participants

Thirty participants (15 males and 15 females) in their 20s and 30s participated in the experiment. Participants were free of musculoskeletal and neurological disorders. All participants signed an informed consent form prior to participation. The data collection protocol had been approved by the Institutional Review Board of Seoul National University.

3.4.1.2 Experimental tasks

In this experiment, the participants conducted three experiment tasks each of which consisted of a physical and a WM task simultaneously performed.

The physical task was a navigating task of walking along a predetermined route with loaded backpack. Four different routes were generated for the navigating task (Figure 3.9). All routes were designed to have the same travel distance, and the same level of difficulty based on several criteria, such as the number of direction changes and turning angles. Participants were instructed to complete this task with comfortable gait speed and stride length. Backpack weight was the independent variable of the study and had four levels in relation to the body weight (0, 15, 25 and 40% of body weight, denoted as BW 0, BW 15, BW 25 and BW 40, respectively). The four backpack weight levels for each participant were generated by placing different combinations of weight plates (1, 1.5, 3, 5 and 10kg weights) into a backpack.

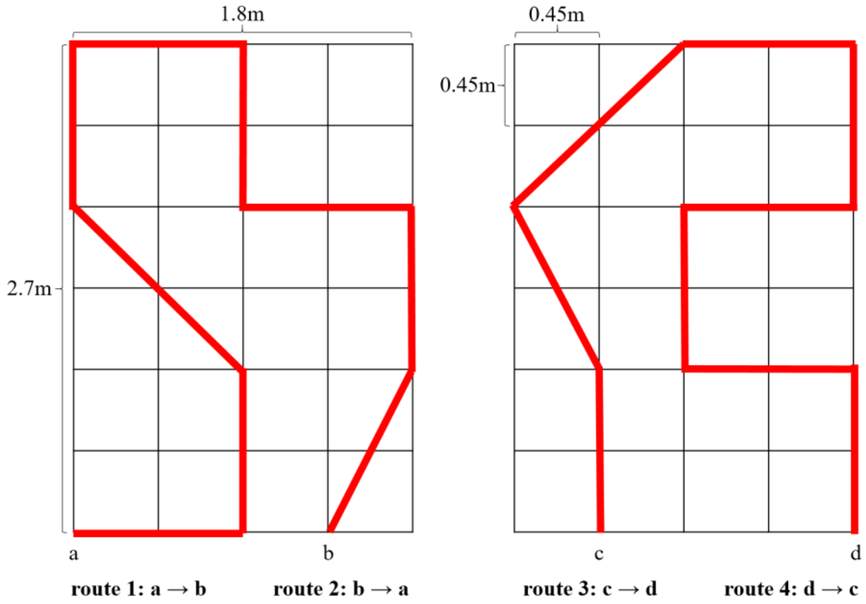


Figure 3.9 Four different routes for the navigating task

As in Section 3.3, different types of WM tasks were presented for the three experiment tasks. They were the Corsi block task (Corsi 1972), digit span task (Wechsler 1939), and 3-back task (Kirchner 1958). They corresponded to the three components of the Baddeley's WM model (the visuo-spatial sketchpad, phonological loop and central executive systems).

The three experiment tasks, each of which required simultaneously performing the navigating task and one of the WM tasks, were named as the V-N (visuo-spatial WM task and navigating), P-N (phonological loop WM task and navigating) and C-N (central executive WM task and navigating) tasks, respectively.

3.4.1.3 Procedures and dependent measures

In this study, each participant performed 12 experiment trials (12 = 4 backpack weight levels × 3 experiment tasks). The order of the 12 trials was randomized for each participant. In each trial, one randomly selected route among the four routes was used for the navigating task. To minimize the effect of fatigue, each participant conducted the 12 trials over a period of two days and plenty of time for rest (minimum of 30 minutes) was given between trials. Prior to the experiment trials, an introduction/training session had been provided to the participants to allow for familiarization with the experimental tasks.

The procedure for the V-N task was as follows: at the beginning of a task trial, the participant stood on a flat surface without a backpack. Then, the participant was presented with the sequence of black circles for the Corsi block task. A monitor screen (27 inches) placed in front of the participant was used to display the sequence. Once the visual information presentation was finished, a random route to perform the navigating task was given by allowing the participant to recognize the experimenter's position; the experimenter was pre-positioned at the starting point of the route. When the participant arrived at the starting point of the route, two experimenters standing by on either side of the participant put the backpack on his/her back. Note that the participant was given the backpack to wear in all conditions, including the condition with no external weight to bear. The participant performed the navigating task while trying to retain the visuo-spatial information. Immediately after the V-N task was finished, the participant took off the backpack with the assistance from the two experimenters and reproduced the sequence of black circles by pointing on the answer sheet presented on the monitor screen. The Corsi block task score was recorded.

The procedure for the P-N task was as follows: at the beginning of a task trial, the participant stood on a flat surface without a backpack. Then, the participant was presented with auditory stimuli (ten numbers) according to the protocol of the digit span task. At the completion of the auditory information presentation, a random route to perform the navigating task was given. When the participant arrived at the starting point of the route, the experimenters put the backpack on the participant's back similarly to the V-N task. Then, the participant performed the navigating task while trying to retain the auditory information. Immediately after the P-N task was finished, the participant took off the backpack again with the assistance from the two experimenters and reproduced the auditory stimuli by speaking. The digit span task score was recorded.

The procedure for the C-N task was as follows: at the beginning of a trial, the participant moved to the starting point of the route after receiving a random route to perform the navigating task, and then received the target number for the 3-back task; the experimenters put the backpack on the participant's back. Then, the participant performed the navigating and 3-

back tasks simultaneously. The participant was instructed to verbally respond immediately when the target number was presented. The 3-back task score was recorded.

For all three experiment tasks, behavioural, physiological, and psychophysical response data, which were thought to be helpful in understanding the effects of backpack weight on WM task performance, were collected from the participants during or after each task trial. Three types of gait performance variables (task completion time, gait speed and stride length) were measured while the participant was performing the three experiment tasks. Among various gait performance parameters, task completion time, gait speed and stride length were employed in this study as they had been widely utilized in research studies (Baram et al. 2002; Griffin et al. 2011; Hollman, McDade, and Petersen 2011; Shores 1980). For the C-N task, task completion time was not measured since it was the same as the 3-back task execution time, and was constant for all trials. The three gait performance parameters are described in Table 3.3.

Table 3.3 Gait performance measures

Measure	Unit	Description
Task completion time	sec	Amount of time required for navigating task to be completed
Gait speed	m/s	Calculated by dividing the distance walked by the ambulation time

Stride length	meter	Anterior-posterior distance between heels of two consecutive footprints of the same foot (left to left, right to right)

Heart rate was measured right after each task trial using Samsung gear fit 2. Additionally, each participant conducted subjective ratings of physical discomfort and mental workload immediately after each task trial. The Borg CR10 scale (Borg 1982) was employed.

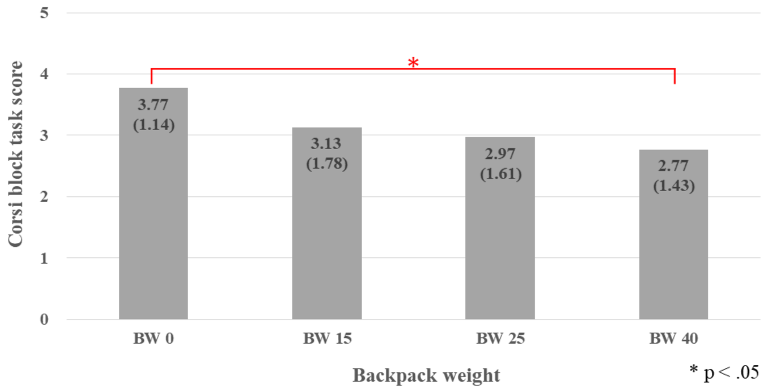
3.4.1.4 Data analyses

For each of the three experiment tasks, one-way repeated measures ANOVA was conducted to test the effect of backpack weight on the corresponding WM task score and other dependent measures (behavioural, physiological, and psychophysical measures). Mauchly's test was performed to assess the sphericity of data for each ANOVA. In cases where sphericity was violated, the degrees of freedom were corrected – the Greenhouse-Geisser correction was used when the Greenhouse-Geisser estimate of sphericity (ε) was less than 0.75; otherwise, the Huynh-Feldt correction was used (Field 2009). In the case of significant ANOVA results, post-hoc Bonferroni multiple pairwise comparisons were conducted. Bonferroni corrections were made. All statistical tests were conducted using IBM SPSS Statistics 23.0, and were based on an alpha level of 0.05.

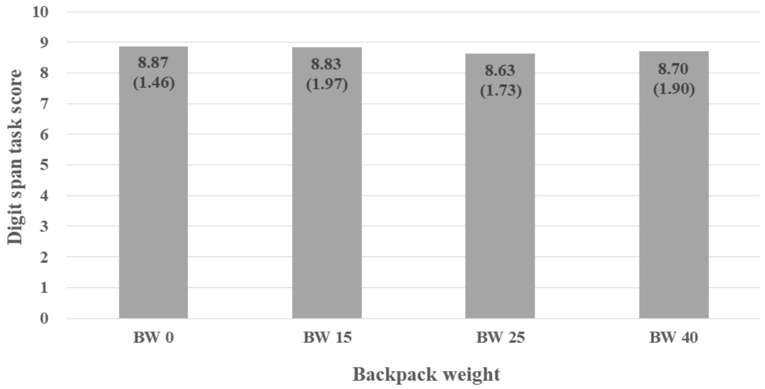
3.4.2 Results

3.4.2.1 Working memory task scores

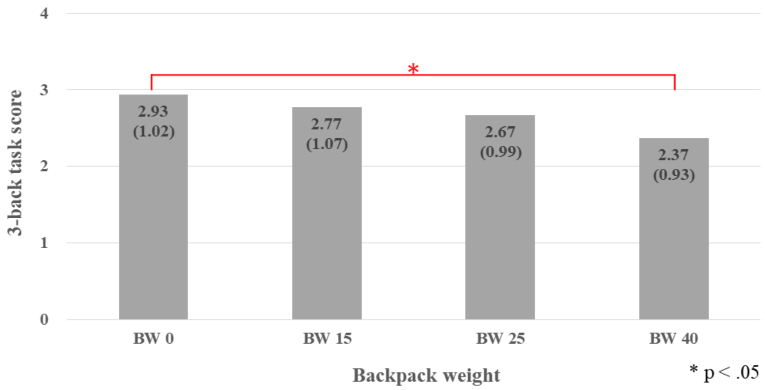
The ANOVAs revealed that backpack weight had a significant effect on the visuo-spatial and central executive WM task scores (F=3.402 and 3.707 for the V-N and C-N tasks, respectively, p<.05). For the V-N and C-N tasks, WM task performance decreased as backpack weight increased. On the other hand, there was no significant difference in phonological loop WM task scores (F=.197, p>.05). Figure 3.10 visually depicts the backpack weight effects.



(a) V-N task



(b) P-N task

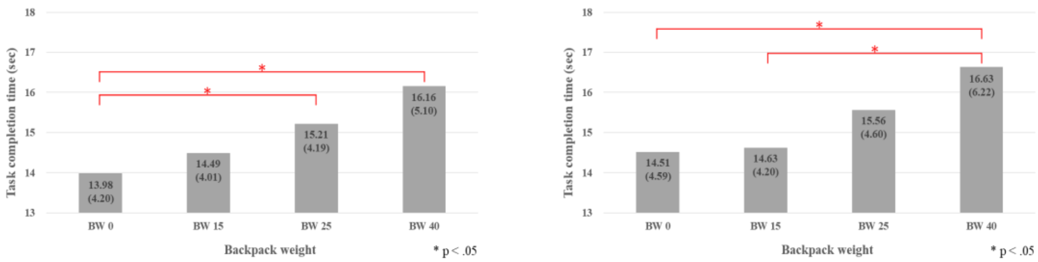


(c) C-N task

Figure 3.10 Effects of backpack weight on WM task scores

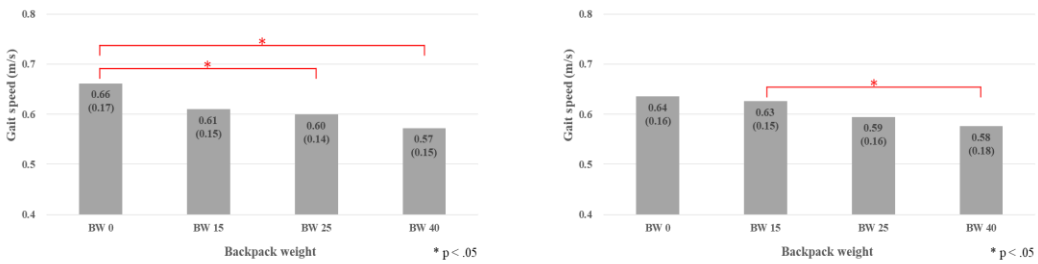
3.4.2.2 Gait performance measures

The ANOVAs indicated that backpack weight significantly affected all three gait performance measures for each of the three experiment tasks (F=6.554, 4.847 and 4.644 for the V-N, P-N and C-N tasks, respectively, p<.05). As backpack weight increased, all of the three gait performance measures showed a tendency to decrease. Figures 3.11-3.13 visually depict the effects of backpack weight on the three gait performance measures (task completion time, gait speed and stride length), respectively.

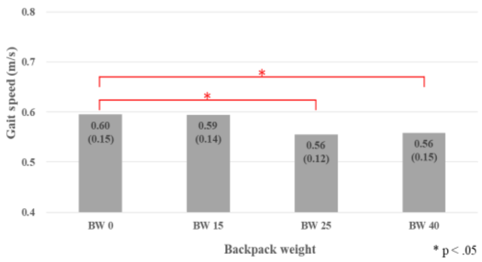


(a) V-N task **(b) P-N task**

Figure 3.11 Effects of backpack weight on task completion time

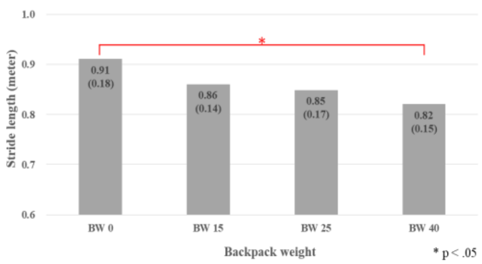


(a) V-N task **(b) P-N task**

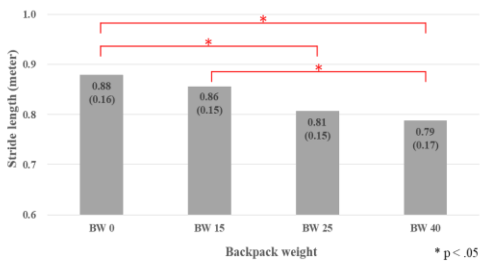


(c) C-N task

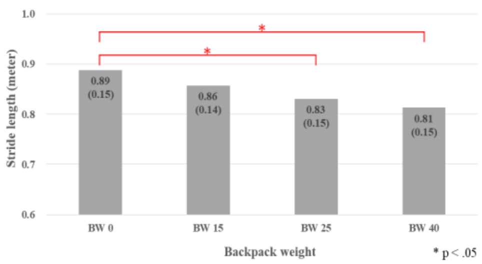
Figure 3.12 Effects of backpack weight on gait speed



(a) V-N task



(b) P-N task

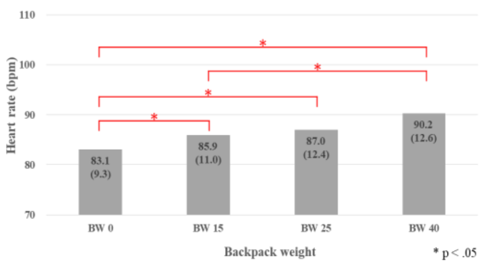


(c) C-N task

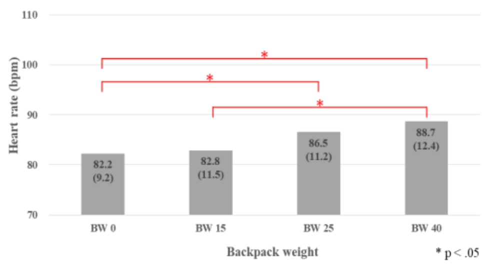
Figure 3.13 Effects of backpack weight on stride length

3.4.2.3 Heart rate

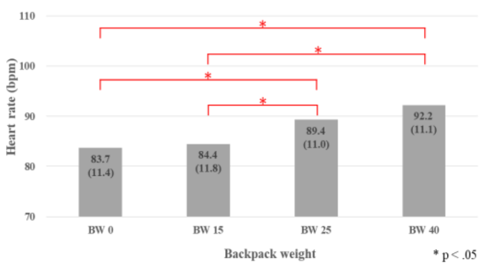
The ANOVA found that backpack weight significantly affected heart rate in all three experiment tasks (F=10.133, 14.365 and 20.846 for the V-N, P-N and C-N tasks, respectively, $p<.05$). As backpack weight increased, heart rate increased for all of the three experiment tasks. Figure 3.14 visually depicts the backpack weight effects.



(a) V-N task



(b) P-N task

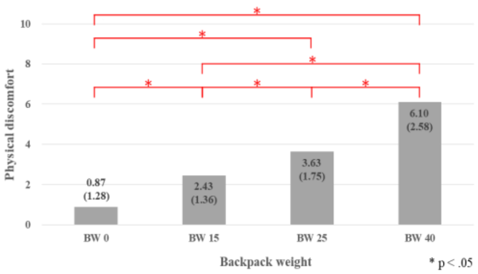


(c) C-N task

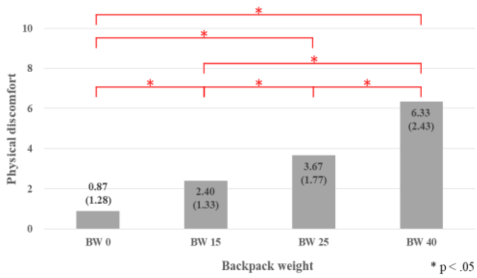
Figure 3.14 Effects of backpack weight on heart rate

3.4.2.4 Physical discomfort and mental workload

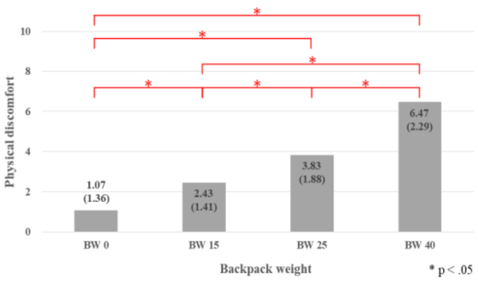
The ANOVA results indicated that backpack weight significantly affected both the physical discomfort and mental workload ratings for all three experimental tasks (F=72.351, 83.428 and 81.127 for the V-N, P-N and C-N tasks, respectively, p<.05). As backpack weight increased, physical discomfort and mental workload ratings increased for all of the three experiment tasks. Figures 3.15-3.16 visually depict the effects of backpack weight.



(a) V-N task

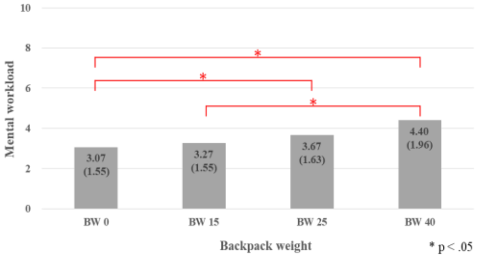


(b) P-N task

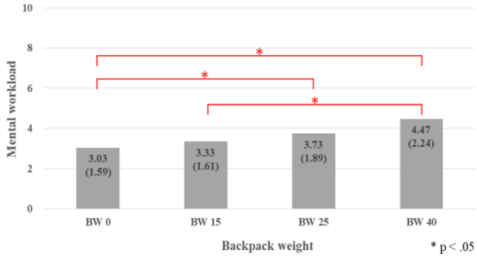


(c) C-N task

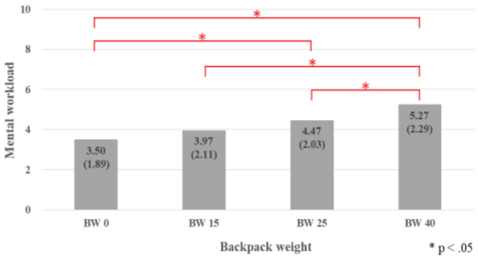
Figure 3.15 Effects of backpack weight on physical discomfort



(a) V-N task



(b) P-N task



(c) C-N task

Figure 3.16 Effects of backpack weight on mental workload

3.4.3 Discussion

The objective of the current study was to empirically investigate the effects of backpack weight (body-worn equipment weight) on a worker's performance of basic WM tasks while the worker is simultaneously performing the navigating task with loaded backpack. Backpack weight had four levels (0, 15, 25 and 40% of the worker's body weight). Three WM tasks, that is, the Corsi block, digit span and 3-back tasks, were considered so as to examine the different sub-components of the WM system, that is, the visuo-spatial sketchpad, phonological loop and central executive systems. The scores of the three WM tasks and a set of measures pertinent to gait performance, heart rate, physical discomfort and perceived mental workload were employed as the dependent variables of the study. Statistical analyses were conducted to test the effects of backpack weight on the dependent variables.

The results of data analyses showed that backpack weight affected WM task scores differently in regards to the type of WM task. For the V-N and C-N tasks, WM task performance decreased as backpack weight increased (Figures 3.10a and 3.10c). On the other hand, there was a nonsignificant effect of the backpack weight for the P-N task (Figure 3.10b). Also, as backpack weight increased, all of the three gait performance measures showed a tendency to decrease while heart rate, physical discomfort rating, and mental workload rating showed a tendency to increase (Figures 3.11-3.16).

The observed backpack weight effects on the visuo-spatial and central executive WM task performance (Figures 3.10a and 3.10c), that is, decreases in WM task performance resulting from increased backpack weight, could be explained largely in terms of the limited attentional resources of the human information processing system.

As mentioned in Section 3.3.3, a human operator has a limited capacity of attention resources (Broadbent 2013; Kahneman 1973; Pashler and Sutherland 1998; Treisman 1960; Wickens et al. 2013). If the total attention demand of concurrent tasks exceeds the human capacity, the performance of one or more of these tasks will suffer (Wickens et al. 2013). In this study, each experiment trial required the participants to simultaneously perform the navigating task (with loaded backpack) and a WM task. The navigating task required the participant to walk along a route while maintaining body balance, which is accomplished through feedback (compensatory reactive postural responses) and feedforward control (anticipatory postural control) (Shumway-Cook and Woollacott 2007). Such postural control requires attentional resources (Kerr, Condon, and McDonald 1985; Lajoie et al. 1993, 1996; Shumway-Cook et al. 1997; Teasdale et al. 1993). Also, each of the three WM tasks employed in this study demands attentional resources as it requires the participants to perceive information in the environment and maintain it through rehearsal (Wickens et al. 2013). It is thought that in each of the three experiment tasks, increased backpack weight increased the difficulty of the navigating task. This may be explained due to the centre of gravity

(CoG) reaching the limits of base support, causing more effort to be needed to recover anteroposterior stability, meaning balance control becomes more difficult. Therefore, this may increase the amount of attention allocated to the physical task, which may have led to the shortage of available resources for the concurrent WM task and eventually a performance decrease. The increases in perceived mental workload associated with increased backpack weight, shown in Figures 3.16a and 3.16c, are thought to reflect the progressive reduction of attentional resources available for the WM tasks resulting from backpack weight increases.

The observed backpack weight effects on the performance of the WM tasks could also be explained on the basis of the neural mechanisms underlying different physical and mental tasks. From the neuroscience point of view, two tasks performed simultaneously are considered interfering with each other when their individual patterns of brain activation have a significant overlap, in other words, when they utilize the very same population of neurons (Klingberg and Roland 1997; Klingberg 1998; Passingham 1996; Rémy et al. 2010; Roland and Zilles 1998; Wu, Kansaku, and Hallett 2004). This neuroscience view on between-task interference is similar to the idea that concurrent tasks interfere with one another when they compete for limited attentional resources.

The participants in this study conducted three experiment tasks, each of which required simultaneously conducting a navigating and a WM task.

According to existing neuroscience studies, the navigating task activates the following brain areas: primary motor cortex (M1), S1, SMA, PMC, occipital area (primary visual cortex), posterior parietal cortex, midline cerebellum (vermal/paravermal cerebellum) and basal ganglia (Ashe et al. 2006; Drew 1993; Fukuyama et al. 1997; Grafton, Fagg, and Arbib 1998; la Fougère et al. 2010; Miyai et al. 2001; Roland et al. 1980; Shibasaki et al. 1993; Suzuki et al. 2004; Wang et al. 2008).

Visuo-spatial WM tasks have been reported to activate the VLPFC, posterior parietal cortex, PMC, occipital area, and ACC (Awh, Jonides, and Smith 1996; Awh and Jonides 1998; Cohen et al. 1997; Courtney et al. 1997; Fiez et al. 1996; Gluck, Mercado, and Myers 2013; Haxby, Grady, and Horwitz 1991; Kammer et al. 1997; Klingberg 1998; Na et al. 2000; Salmon et al. 1996; Ungerleider 1995). Hence, the navigating and visuo-spatial WM tasks of the V-N task of the current study have an overlap of brain activation in the posterior parietal cortex, PMC, and occipital area, and, thus, can be thought of as interfering with each other.

Central executive WM tasks are known to activate the DLPFC, VLPFC, primary auditory cortex, PMC, SMA, posterior parietal cortex, posterior-lateral cerebellum, ACC, and thalamus (Courtney et al. 1997; Gluck, Mercado, and Myers 2013; Henson, Shallice, and Dolan 1999; Jonides et al. 1993; Klingberg 1998; Na et al. 2000; Nyberg, Cabeza, and Tulving 1996; Owen 2000; Owen et al. 2005; Wagner et al. 1998; Wagner et al. 1998). Thus, the navigating and central executive WM tasks of the C-N task of the current study can be regarded as interfering with each other as they have an overlap of brain activation in the PMC, posterior parietal cortex, and SMA.

As described above, each of the two experiment tasks (the V-N and C-N tasks) is subject to dual-task interference as the navigating and WM task constituting it have a significant overlap of neural activation in brain areas. As backpack weight increases, the amount of neuronal resources used by the navigating task would increase leading to increased dual task interference and thus decreased WM task performance.

The observed effects of backpack weight on WM task performance (Figures 3.10a and 3.10c) may also be attributed to the impacts of negative emotional experience on human information processing. The detailed description is the same as in Section 3.3.3. In the current study, perceived physical discomfort was found to increase as backpack weight increased (Figures 3.15a and 3.15c). Also, heart rate increased as backpack weight increased indicating an increase in physical and mental workload (Figures 3.14a and 3.14c). These changes associated with increased backpack weight may have caused increases in negative emotions, have caused narrowing of attentional scope, and have further disrupted the WM tasks.

The above accounts of the study findings on the basis of the impacts of negative emotional experience are further supported by the neural mechanism of discomfort/pain perception. The detailed descriptions related to this process are same as mentioned in Section 3.3.3. The muscle pain increases as the load weight imposed on the body increases, and such a neural mechanism that carries out pain perception may act as interference in completing a WM task.

This study evaluated the gait performance during the simultaneous completion of the navigating and WM tasks (Figures 3.11-3.13). With this information, it was possible to investigate the change in the gait performance and WM performance according to the backpack weight. As shown in Figures 3.11-3.13, all three types of gait performance measures had a tendency to decrease as backpack weight increased, for all experiment tasks. Therefore, considering these results together with the results for the WM task performance in Figure 3.10, both the gait performance and WM task performance decreased as backpack weight increased during the V-N task and C-N task. Meanwhile, in the P-N task, as backpack weight increased, the gait performance decreased while WM task performance did not show any significant difference. Such a phenomenon can be explained by multiple resource theory (Wickens 1991) and threaded cognition (Salvucci and Taatgen 2008), with relation to information processing. When people have separate tasks to perform concurrently, they need to divide their attention to maintain good levels of performance in both tasks (Wickens and Hollands 2000). According to the multiple resource theory, there are two main processing codes, spatial and verbal. If two tasks require different resources, parallel processing with divided attention becomes easier, leading to better dual-task performance (Wickens 1991, 2002). However, if two tasks require the same processing code, the performance of one or more of these tasks can be decreased due to the significant dual-task interference (Wickens 1991). That is, if two tasks require the same resources, then priority is allocated to the primary task, which is deemed more important, while the other task will be considered as a secondary task, resulting in the degradation of dual-task performance (Baddeley 1992; Wickens 1980). There is also a similar theory of threaded cognition (Salvucci and Taatgen 2008), which explains information processing according to within-resource seriality but between-resource parallelism. This theory states that two tasks can be simultaneously completed when separate resources are used, but in the case when a particular resource is required in both tasks, tasks are completed one operation at a time, resulting in the reduction of task performance.

The navigating task used in this study requires the participant to walk along a particular route while maintaining body balance, and thus requires the visuo-spatial and central executive resources (Amboni, Barone, and Hausdorff 2013; Fukuyama et al. 1997; la Fougère et al. 2010; Persad et al. 2008; Shumway-Cook and Woollacott 2007; Van Iersel et al. 2008). In particular, since the navigating task is performed with various weights in the backpack, it takes a lot of effort to maintain the body balance, requiring visuo-spatial (especially, peripheral vision) and central executive resources (Manchester et al. 1989; Paulus, Straube, and Brandt 1984; Shumway-Cook and Woollacott

2007). Therefore, completing the visuo-spatial and central executive WM tasks while completing the navigating task would require the use of the same processing code. This use of the same processing code would result in significant dual-task interference, and parallel processing with divided attention would become difficult. Additionally, as backpack weight increased, the balance control would become more difficult. As a result, the priority would be allocated to the navigating task and more visuo-spatial and central executive resources would be used. Accordingly, the WM task would be considered as a secondary task, thus further decreasing the performance for the visuo-spatial and central executive WM tasks. On the other hand, completing the phonological loop WM task while completing the navigating task would require different processing codes; thus, there would be less dual-task interference. Therefore, it can be inferred that there was no degradation of the phonological loop WM task performance even as backpack weight increased. The decrease in the gait performance can be interpreted as a result of postural control becoming more difficult as backpack weight increased.

3.5 Standing, navigating and walking tasks

3.5.1 Method

The methods for the standing and navigating tasks were described in Section 3.3 and 3.4, respectively. In this section, the method for the walking task was described.

3.5.1.1 Participants

Thirty participants (15 males and 15 females) in their 20s and 30s participated in the experiment. Participants were free of musculoskeletal and neurological disorders. All participants signed an informed consent form prior to participation. The data collection protocol had been approved by the Institutional Review Board of Seoul National University.

3.5.1.2 Experimental tasks

In this experiment, the participants conducted three experiment tasks each of which consisted of a physical and a WM task simultaneously performed.

The physical task was a walking task of walking along straight, marked path for 15 seconds. During this task, each participant selected a comfortable stride time and stride length, which was constant for each experiment task. Stride time is defined as the time elapsed between the initial contacts of two consecutive footfalls of the same foot (Hollman, McDade, and Petersen 2011), and was controlled by a vibrating metronome placed on the right upper arm. Stride length is defined as the anterior-posterior distance between heels of two consecutive footprints of the same foot (Hollman, McDade, and Petersen 2011), and was controlled by strips of tape placed along the floor.

Backpack weight was the independent variable of the study and had four levels in relation to the body weight (0, 15, 25 and 40% of body weight, denoted as BW 0, BW 15, BW 25 and BW 40, respectively).

As in Section 3.3 and 3.4, three types of WM tasks were presented for the three experiment tasks. They were the Corsi block task (Corsi 1972), digit span task (Wechsler 1939), and 3-back task (Kirchner 1958).

The three experiment tasks, each of which required simultaneously performing the walking task and one of the WM tasks, were named as the V-W (visuo-spatial WM task and walking), P-W (phonological loop WM task and walking) and C-W (central executive WM task and walking) tasks, respectively.

3.5.1.3 Procedures and dependent measures

In this study, each participant performed 12 experiment trials (12 = 4 backpack weight levels × 3 experiment tasks). The order of the 12 trials was randomized for each participant. To minimize the effect of fatigue, each participant conducted the 12 trials over a period of two days and plenty of time for rest (minimum of 30 minutes) was given between trials. Prior to the experiment trials, an introduction/training session had been provided to the participants to allow for familiarization with the experimental tasks.

The procedure for the V-W task was as follows: at the beginning of a task trial, the participant stood on the flat surface without a backpack. Then, the participant was presented with the sequence of black circles for the Corsi block task. A monitor screen (27 inches) placed in front of the participant was used to display the sequence. At the completion of the visuo-spatial information presentation, two experimenters standing by on either side of the participant put the backpack on his/her back. Note that the participant was given the backpack to wear in all conditions, including the condition with no external weight to bear. The participant performed walking for 15 seconds while trying to retain the visuo-spatial information. Immediately after the 15 seconds time interval, the participant took off the backpack with the assistance from the two experimenters and reproduced the sequence of black circles by pointing on the answer sheet presented on the monitor screen. The Corsi block task score was recorded.

The procedure for the P-W task was as follows: at the beginning of a task trial, the participant stood on the flat surface without a backpack. Then, the participant was presented with auditory stimuli (ten numbers) according to the protocol of the digit span task. At the completion of the auditory information presentation, the experimenters put the backpack on the participant's back similarly to the V-W task. The participant performed walking for 15 seconds while trying to retain the auditory information. Immediately after the 15 seconds time interval, the participant took off the backpack again with the assistance from the two experimenters and reproduced the auditory stimuli by speaking. The digit span task score was recorded.

The procedure for the C-W task was as follows: at the beginning of a trial, the participant stood on the flat surface without a backpack, as in the other two tasks, and, received the target number for the 3-back task; the experimenters put the backpack on the participant's back. Then, the participant performed the walking and 3-back tasks simultaneously. The participant was instructed to verbally respond immediately when the target number was presented. The 3-back task score was recorded.

For all three experiment tasks, physiological and psychophysical response data, which were thought to be helpful in understanding the effects of backpack weight on WM task performance, were collected from the participants after each task trial. Heart rate was measured right after each task trial using Samsung gear fit 2. Additionally, each participant conducted subjective ratings of physical discomfort and mental workload immediately after each task trial. The Borg CR10 scale (Borg 1982) was employed.

3.5.1.4 Data analyses

For each of the three experiment tasks, two-way repeated measures ANOVA was conducted to examine whether the effects of backpack weight on the WM task performance and other dependent measures depend on the type of physical task.

Mauchly's test was performed to assess the sphericity of data for each ANOVA. In cases where sphericity was violated, the degrees of freedom were corrected – the Greenhouse-Geisser correction was used when the Greenhouse-Geisser estimate of sphericity (ε) was less than 0.75; otherwise, the Huynh-Feldt correction was used (Field 2009). In the case of significant ANOVA results, post-hoc Bonferroni multiple pairwise comparisons were conducted. Bonferroni corrections were made. All statistical tests were conducted using IBM SPSS Statistics 23.0, and were based on an alpha level of 0.05.

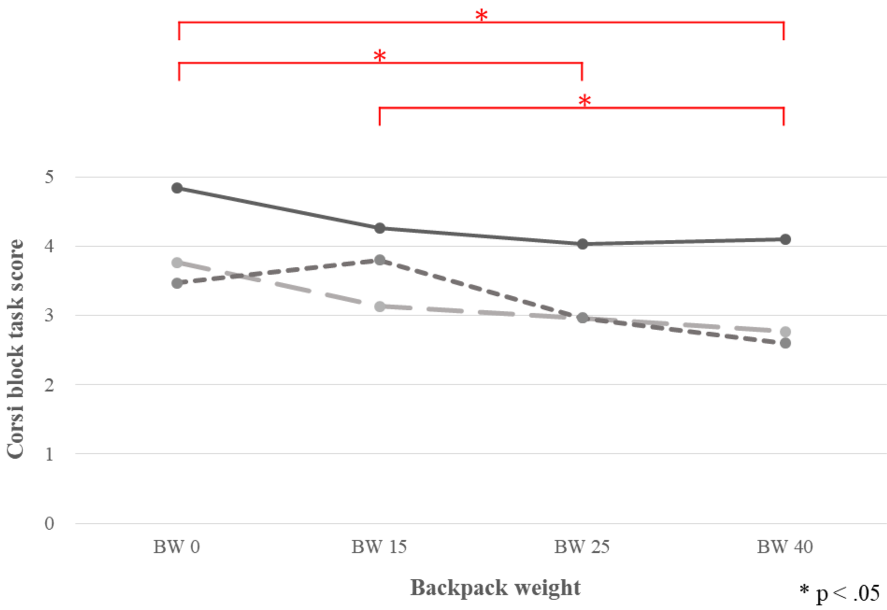
3.5.2 Results

3.5.2.1 Working memory task scores

The ANOVA revealed that there was a significant main effect of the backpack weight on the visuo-spatial WM task score ($F=10.649$, $p<.05$). As backpack weight increased, the WM task score decreased. There was also a significant main effect of the physical task type ($F=31.529$, $p<.05$). In conditions with same backpack weight level, WM task score was distinctly lower for the navigating and walking tasks compared to the standing task. An interaction effect between the backpack weight and physical task type was not significant ($F=1.664$, $p>.05$). Figure 3.17a visually depicts the effects of backpack weight and physical task type. The results of the post-hoc Bonferroni multiple pairwise comparisons are also presented.

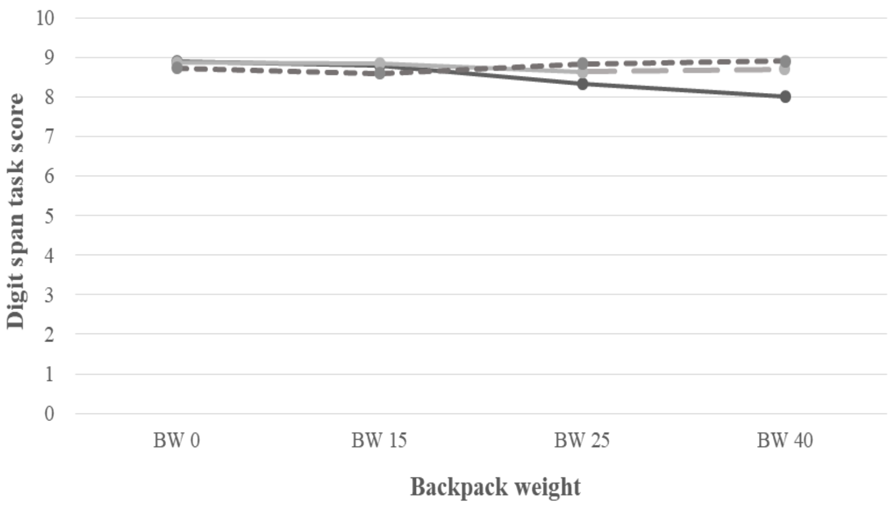
For the phonological loop WM task score, all effects are reported as non-significant. No main effects of the backpack weight and physical task type were observed ($F=.809$ and 1.078 for the backpack weight and physical task type, respectively, $p>.05$). There was a non-significant interaction effect between the backpack weight and physical task type ($F=1.495$, $p>.05$). Figure 3.17b presents the mean WM task scores for the twelve experiment conditions (12 conditions = 4 levels of backpack weight × 3 physical task types).

For the central executive WM task score, both main effects of the backpack weight and physical task type were significant (F=14.801 and 13.848 for the backpack weight and physical task type, respectively, p<.05). As backpack weight increased, the WM task score decreased. In conditions with same backpack weight level, WM task score was distinctly lower for the walking task compared to the standing and navigating tasks. A significant interaction effect between the backpack weight and physical task type was observed (F=3.190, p<.05). Figure 3.17c visually depicts the main and interaction effects.



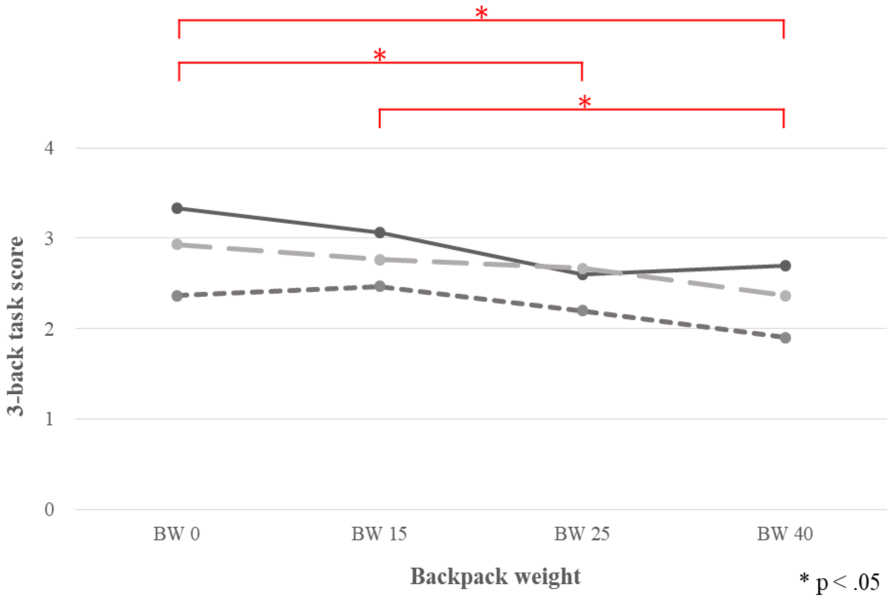
	BW 0	BW 15	BW 25	BW 40
Standing	4.83 (0.53)	4.27 (1.20)	4.03 (1.16)	4.10 (1.40)
Navigating	3.77 (1.14)	3.13 (1.78)	2.97 (1.61)	2.77 (1.43)
Walking	3.47 (1.25)	3.80 (1.19)	2.97 (1.40)	2.60 (1.54)

(a) Visuo-spatial WM task and physical task



	BW 0	BW 15	BW 25	BW 40
Standing	8.90 (1.49)	8.80 (1.35)	8.33 (1.88)	8.00 (2.15)
Navigating	8.87 (1.46)	8.83 (1.97)	8.63 (1.73)	8.70 (1.90)
Walking	8.73 (1.60)	8.60 (1.85)	8.83 (1.60)	8.90 (1.35)

(b) Phonological loop WM task and physical task



	BW 0	BW 15	BW 25	BW 40
Standing	3.33 (0.76)	3.07 (0.83)	2.60 (0.97)	2.70 (0.95)
Navigating	2.93 (1.01)	2.77 (1.07)	2.67 (0.99)	2.37 (0.93)
Walking	2.37 (0.93)	2.47 (0.73)	2.20 (0.96)	1.90 (0.89)

(c) Central executive WM task and physical task

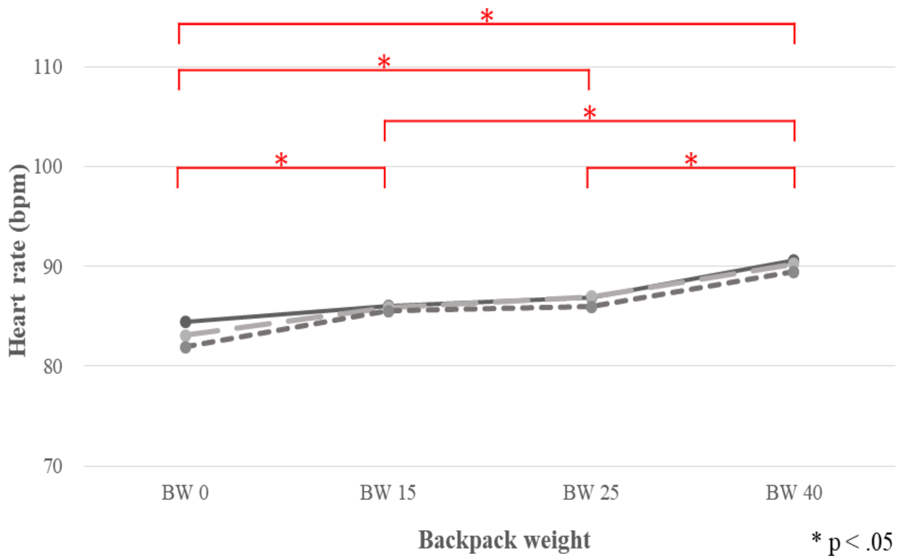
Figure 3.17 Effects of backpack weight and physical task type on WM task scores

3.5.2.2 Heart rate

The ANOVA found that there was a significant main effect of the backpack weight on the heart rate, for the visuo-spatial WM task ($F=35.813$, $p<.05$). As backpack weight increased, heart rate increased. No main effect of the physical task type was observed ($F=.532$, $p>.05$). An interaction effect between the backpack weight and physical task type was also non-significant ($F=.296$, $p>.05$). Figure 3.18a visually depicts the effect of backpack weight.

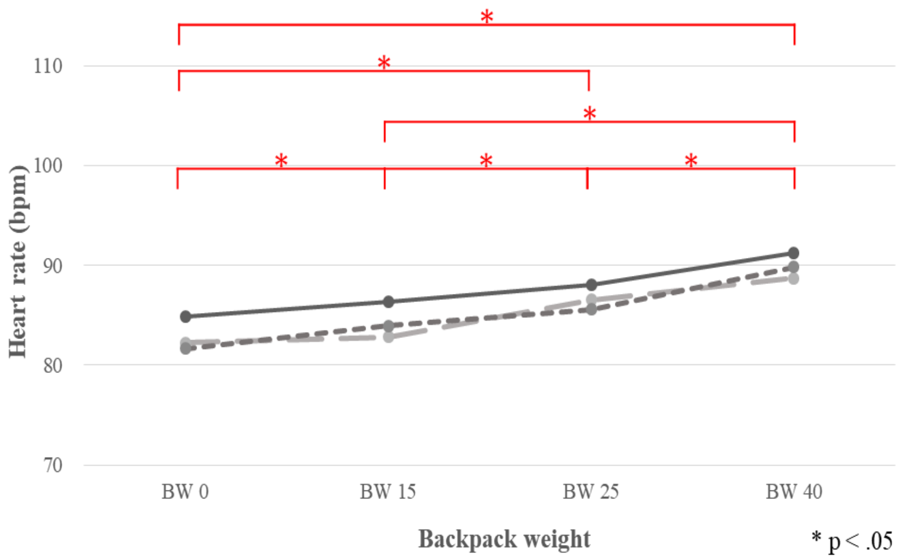
For the phonological loop WM task, both main effects of the backpack weight and physical task type were significant ($F=50.316$ and 3.897 for the backpack weight and physical task type, respectively, $p<.05$). As backpack weight increased, heart rate increased. The heart rate was observed to be higher for the P-S task in comparison to the P-W task. There was a nonsignificant interaction effect between the backpack weight and physical task type ($F=.755$, $p>.05$). Figure 3.18b visually depicts the effects of backpack weight and physical task type.

For the central executive WM task, a main effect of the backpack weight on the heart rate was significant ($F=60.966$, $p<.05$). As backpack weight increased, heart rate increased. There was a nonsignificant main effect of the physical task type ($F=.512$, $p>.05$). There was also a nonsignificant interaction effect between the backpack weight and physical task type ($F=.876$, $p>.05$). Figure 3.18c visually depicts the effect of backpack weight.



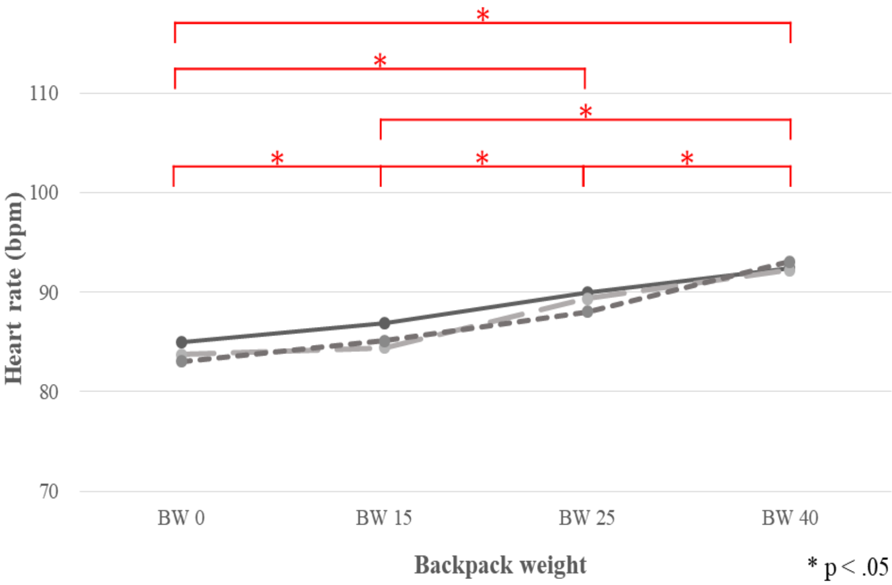
	BW 0	BW 15	BW 25	BW 40
Standing	84.4 (11.6)	86.0 (11.9)	86.9 (11.2)	90.6 (11.8)
Navigating	83.1 (9.3)	85.9 (11.0)	87.0 (12.4)	90.2 (12.6)
Walking	81.9 (9.8)	85.5 (10.7)	85.9 (11.0)	89.5 (11.2)

(a) Visuo-spatial WM task and physical task



	BW 0	BW 15	BW 25	BW 40
Standing	84.9 (10.9)	86.3 (10.5)	88.1 (11.1)	91.3 (11.0)
Navigating	82.2 (9.2)	82.8 (11.5)	86.5 (11.2)	88.7 (12.4)
Walking	81.7 (8.8)	83.9 (9.7)	85.6 (10.1)	89.8 (11.0)

(b) Phonological loop WM task and physical task



	BW 0	BW 15	BW 25	BW 40
Standing	84.9 (11.9)	86.8 (10.9)	90.0 (14.0)	92.4 (12.7)
Navigating	83.7 (11.4)	84.4 (11.8)	89.4 (11.0)	92.2 (11.1)
Walking	83.0 (8.1)	85.1 (8.0)	88.0 (9.1)	93.1 (11.2)

(c) Central executive WM task and physical task

Figure 3.18 Effects of backpack weight and physical task type on heart rate

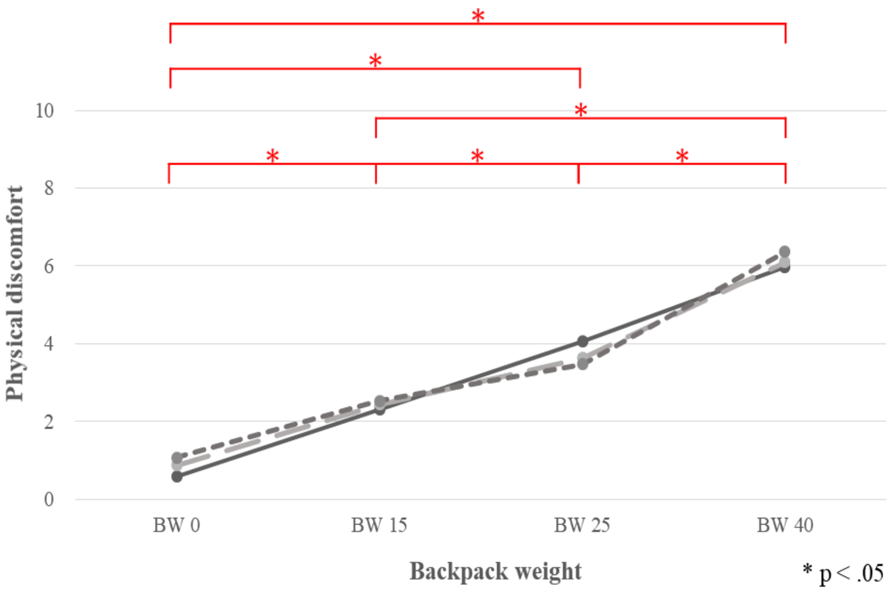
3.5.2.3 Physical discomfort and mental workload

The ANOVA results for the physical discomfort ratings were as follows: there was a significant main effect of the backpack weight for the visuo-spatial WM task ($F=126.110$, $p<.05$). As backpack weight increased, physical discomfort rating increased. There was a nonsignificant main effect of the physical task type ($F=.270$, $p>.05$). An interaction effect between the backpack weight and physical task type was also non-significant ($F=2.212$, $p>.05$). Figure 3.19a visually depicts the effect of backpack weight.

For the phonological loop WM task, a main effect of the backpack weight on the physical discomfort ratings was significant ($F=115.897$, $p<.05$). As backpack weight increased, physical discomfort rating increased. On the other hand, there was a nonsignificant main effect of the physical task type ($F=1.128$, $p>.05$). There was also a nonsignificant interaction effect between the backpack weight and physical task type ($F=1.546$, $p>.05$). Figure 3.19b visually depicts the effect of backpack weight.

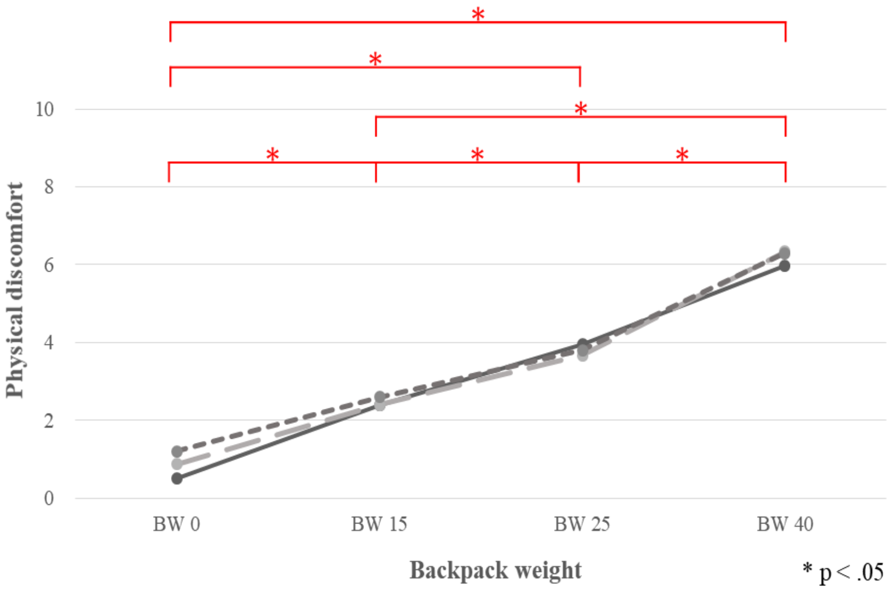
For the central executive WM task, both main effects of the backpack weight and physical task type on the physical discomfort ratings were significant ($F=126.222$ and 3.210 for the backpack weight and physical task type, respectively, $p<.05$). As backpack weight increased, physical discomfort rating increased. An interaction effect between the backpack weight and physical task type was also significant ($F=2.386$, $p<.05$). Figure

3.19c visually depicts the main and interaction effects.



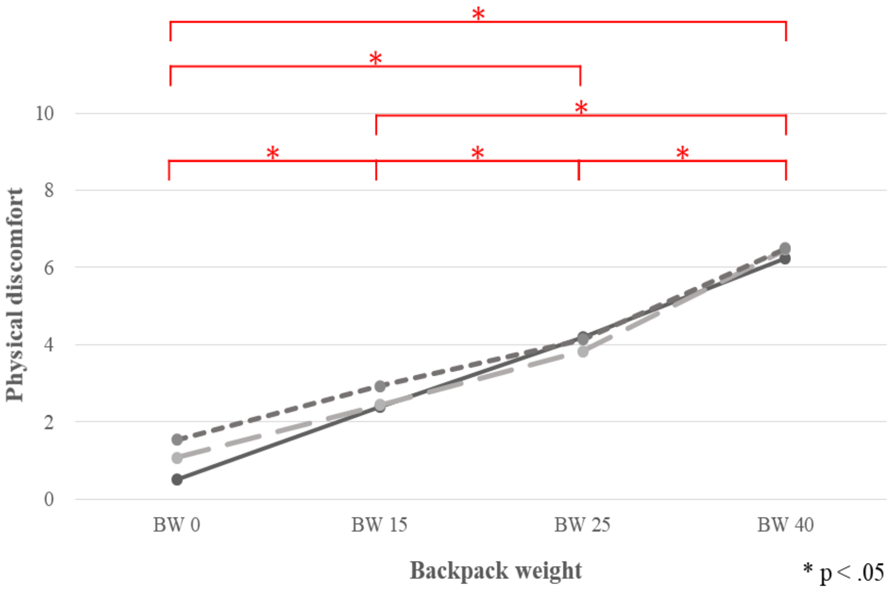
	BW 0	BW 15	BW 25	BW 40
Standing	0.60 (1.13)	2.30 (1.47)	4.07 (2.20)	5.97 (2.41)
Navigating	0.87 (1.28)	2.43 (1.36)	3.63 (1.75)	6.10 (2.58)
Walking	1.07 (1.55)	2.53 (1.57)	3.47 (1.93)	6.37 (2.33)

(a) Visuo-spatial WM task and physical task



	BW 0	BW 15	BW 25	BW 40
Standing	0.50 (1.11)	2.40 (1.43)	3.97 (2.09)	5.97 (2.46)
Navigating	0.87 (1.28)	2.40 (1.33)	3.67 (1.77)	6.33 (2.43)
Walking	1.20 (1.67)	2.60 (1.57)	3.80 (2.01)	6.30 (2.34)

(b) Phonological loop WM task and physical task



	BW 0	BW 15	BW 25	BW 40
Standing	0.50 (1.01)	2.40 (1.40)	4.20 (2.16)	6.23 (2.24)
Navigating	1.07 (1.36)	2.43 (1.41)	3.83 (1.88)	6.47 (2.29)
Walking	1.53 (1.76)	2.93 (1.78)	4.13 (2.00)	6.50 (2.22)

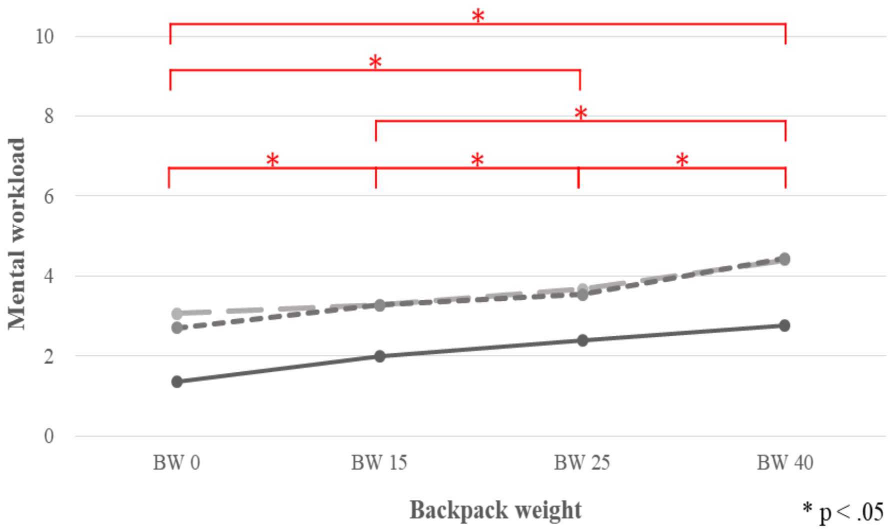
(c) Central executive WM task and physical task

Figure 3.19 Effects of backpack weight and physical task type on physical discomfort

The ANOVAs for the mental workload ratings were as follows: both main effects of the backpack weight and physical task type were significant for the visuo-spatial WM task (F=29.006 and 28.287 for the backpack weight and physical task type, respectively, p<.05). As backpack weight increased, mental workload rating increased. In conditions with same backpack weight level, mental workload rating was distinctly higher for the navigating and walking tasks compared to the standing task. An interaction effect between the backpack weight and physical task type was not significant (F=.912, p>.05). Figure 3.20a visually depicts the effects of backpack weight and physical task type.

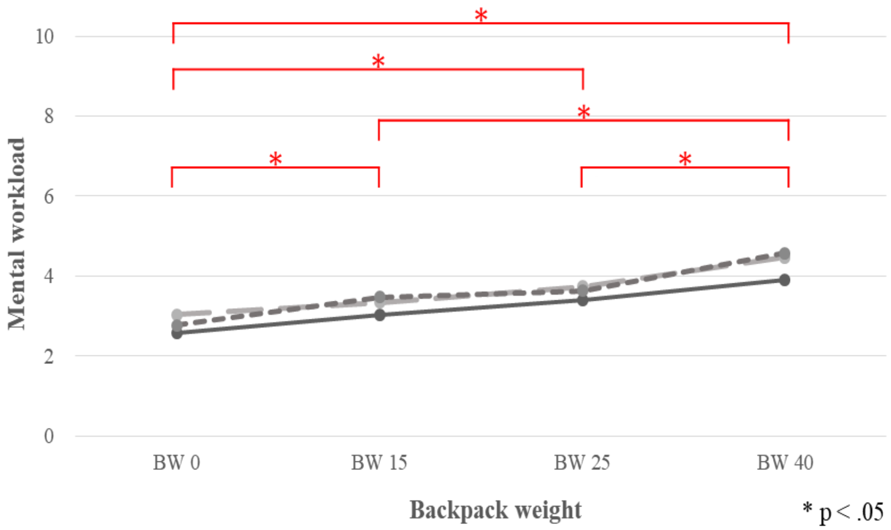
For the phonological loop WM task, there was a significant main effect of the backpack weight on the mental workload ratings ($F=22.530$, $p<.05$). As backpack weight increased, mental workload rating increased. A main effect of the physical task type was nonsignificant ($F=1.992$, $p>.05$). There was also a nonsignificant interaction effect between the backpack weight and physical task type ($F=.637$, $p>.05$). Figure 3.20b visually depicts the effect of backpack weight.

For the central executive WM task, both main effects of the backpack weight and physical task type were significant ($F=22.030$ and 6.940 for the backpack weight and physical task type, respectively, $p<.05$). As backpack weight increased, mental workload rating increased. In conditions with same backpack weight level, mental workload rating was distinctly higher for the walking task compared to the standing and navigating tasks. There was a nonsignificant interaction effect between the backpack weight and physical task type ($F=.825$, $p>.05$). Figure 3.20c visually depicts the effects of backpack weight and physical task type.



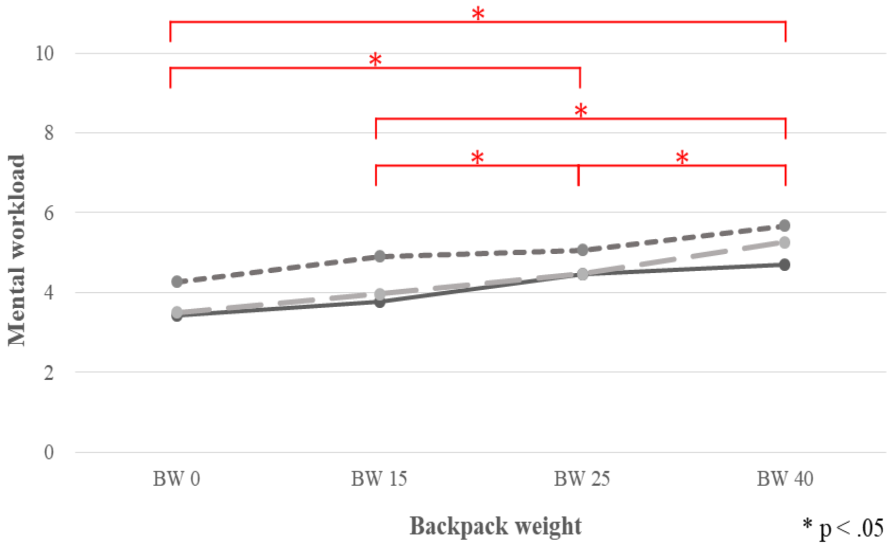
	BW 0	BW 15	BW 25	BW 40
Standing	1.37 (1.30)	2.00 (1.39)	2.40 (1.94)	2.77 (2.00)
Navigating	3.07 (1.55)	3.27 (1.55)	3.67 (1.63)	4.40 (1.96)
Walking	2.70 (1.73)	3.27 (1.82)	3.53 (1.57)	4.43 (1.83)

(a) Visuo-spatial WM task and physical task



	BW 0	BW 15	BW 25	BW 40
Standing	2.57 (1.91)	3.03 (1.92)	3.40 (1.91)	3.90 (2.28)
Navigating	3.03 (1.59)	3.33 (1.60)	3.73 (1.89)	4.47 (2.24)
Walking	2.77 (1.46)	3.47 (1.57)	3.63 (1.69)	4.57 (2.06)

(b) Phonological loop WM task and physical task



	BW 0	BW 15	BW 25	BW 40
Standing	3.43 (2.54)	3.77 (2.40)	4.47 (2.21)	4.70 (2.58)
Navigating	3.50 (1.89)	3.97 (2.11)	4.47 (2.03)	5.27 (2.29)
Walking	4.27 (2.42)	4.90 (2.43)	5.07 (1.93)	5.67 (2.20)

(c) Central executive WM task and physical task

Figure 3.20 Effects of backpack weight and physical task type on mental workload

3.5.3 Discussion

The objective of the current study was to empirically investigate the effects of backpack weight (body-worn equipment weight) and physical task type on a worker's performance of basic WM tasks. Three types of physical tasks were considered in this study. Three WM tasks, that is, the Corsi block, digit span and 3-back tasks, were considered so as to examine the different sub-components of the WM system, that is, the visuo-spatial sketchpad, phonological loop and central executive systems. The scores of the three WM tasks, heart rate, physical discomfort and perceived mental workload were employed as the dependent variables of the study. Statistical analyses were conducted to test the effects of backpack weight and physical task type on the dependent variables.

The results of data analyses showed that backpack weight and physical task type affected WM task scores differently in regards to the type of WM task. Backpack weight and physical task type had a significant effect on the visuo-spatial WM and central executive WM task score (Figures 3.17a and 3.17c). On the other hand, there were no significant effects of the backpack weight and physical task type for the phonological loop WM task score (Figure 3.17b). Also, as backpack weight increased, the heart rate, physical discomfort rating, and mental workload rating increased for all of the nine experiment tasks (Figures 3.18-3.20).

In this study, there were important observations related to the visuo-spatial and central executive WM task scores. In conditions with same backpack weight level, WM task score was distinctly lower for the walking task compared to the standing task (Figures 3.17a and 3.17c). The ANOVA results showed significant main effect in regards to physical task type. These observations can be explained by the difference in the amount of required resources according to the physical task type. Both the standing and walking tasks demand the participant to maintain body balance, and thus required visuo-spatial (especially peripheral vision) and central executive resources (Horak 2006; Manchester et al. 1989; Mihara et al. 2008; Ouchi et al. 1999; Paulus, Straube, and Brandt 1984; Shumway-Cook and Woollacott 2007; Van Iersel et al. 2008). According to Shumway-Cook and Woollacott (2007), “walking is a state of constant falling”. In other words, during gait, the CoG (center of gravity) falls in front of the BoS (base of support), and the person must step forward to re-establish the CoG within the BoS to avoid falling. Therefore, it can be thought that the walking task requires more visuo-spatial and central executive resources than the standing task to maintain balance. Related to this, there was a significant effect of the physical task type on the mental workload ratings for the visuo-spatial and central executive WM tasks. To specify, the mental workload ratings were higher for the walking task compared to the standing task. Also, walking along a straight path is yet another factor that results in the difference in required resources, as it may demand more visuo-spatial resources than standing. These two factors may explain the lower WM task scores for the

V-W and C-W tasks, compared to the V-S and C-S tasks, respectively.

The mean central executive WM task score was distinctly higher for the navigating task compared to the walking task (Figure 3.17c). This may be due to the differences in the experiment task protocol - for the C-N task, the participants completed the task with comfortable gait speed and stride length; on the other hand, for the C-W task, stride time and stride length were controlled. Therefore, it is thought that the walking task required higher level of attention than the navigation task, and, consequently, more attention was available for the central executive working memory task in the C-N task than the C-W task. Higher mental workload ratings for the C-W task compared to the C-N task, shown in Figure 3.20c, seem to reflect the difference in the amount of attention resources available for the WM tasks.

Another important observation was that neither backpack weight nor physical task type significantly affected the phonological loop WM task scores (Figure 3.17b). Such a phenomenon can be explained by the multiple resource theory, with relation to information processing (Wickens 1991). According to the multiple resource theory, there are two main processing codes, spatial and verbal. If two tasks require different processing codes, parallel processing with divided attention becomes easier, leading to less dual-task interference (Wickens 1991, 2002). However, if two tasks require the same processing code, the performance of one or more of these tasks can be decreased due to the significant dual-task interference (Wickens 1991).

There is also a similar theory of threaded cognition (Salvucci and Taatgen 2008), which explains information processing according to within-resource seriality but between-resource parallelism. This theory states that two tasks can be simultaneously completed when separate resources are used, but in the case when a particular resource is required in both tasks, tasks are completed one operation at a time, resulting in the reduction of task performance.

The physical tasks used in this study required the participant to maintain body balance while standing on a flat surface or walking along a path, and thus required visuo-spatial and central executive resources (Amboni, Barone, and Hausdorff 2013; Fukuyama et al. 1997; la Fougère et al. 2010; Persad et al. 2008; Shumway-Cook and Woollacott 2007; Van Iersel et al. 2008). Therefore, completing the visuo-spatial and central executive WM tasks while completing the physical task would require the use of the same processing code. This use of the same processing code would result in significant dual-task interference. On the other hand, when the phonological WM and physical task are executed at the same time, time-sharing efficiency would be improved by using different processing codes, thus less dual-task interference would be expected (Sanders and McCormick 1993; Wickens et al. 2013). Also, since the physical tasks are performed with various weights in the backpack, it takes a lot of effort to maintain the body balance, requiring visuo-spatial (especially, peripheral vision) and central executive resources (Manchester et al. 1989; Paulus, Straube, and Brandt 1984; Shumway-Cook and Woollacott 2007). As the backpack weight increased, the balance control would become more difficult, thus requiring more visuo-spatial and central executive resources. Therefore, when completing the visuo-spatial and central executive WM tasks while completing the physical task, the dual-task interference level would increase as backpack weight increased, thus further decreasing the WM task scores. On the other hand, completing the phonological loop WM task while completing the physical task would require different processing codes; thus, there would be less dual-task interference. Therefore, it can be inferred that there was no degradation of the phonological loop WM task score even as backpack weight increased.

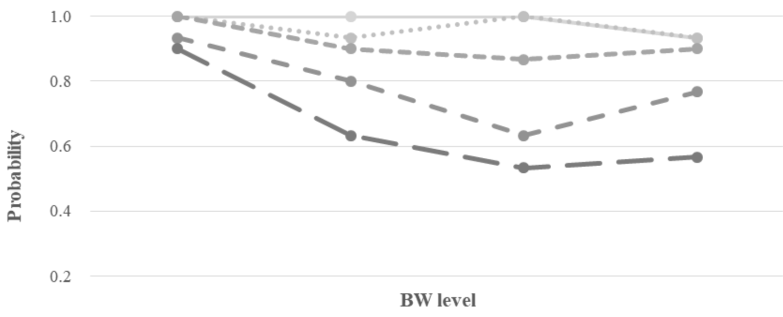
Another observation was that the effect of backpack weight on the central executive WM task score differed according to physical task type (Figure 3.17c). The ANOVA results showed a significant interaction effect between physical task type and backpack weight. An interesting observation was that for the standing task, the WM task score decreased for the BW 15 condition in comparison to the BW 0 condition, but such a reduction in performance was not observed for the walking task. This may be explained by existing research (Hillman et al. 2009; Schaefer et al. 2010) that discuss an increase in mental performance during a moderate-speed walking task, compared to sitting or resting. Additionally, previous research states that the shape of the relationship between aerobic physical workload and mental performance is an inverted-U shape (Brisswalter, Durand, and Delignieres 1995; Joyce et al. 2009; Reilly and Smith 1986). These studies showed results stating that moderate levels of physical workload improved mental performance and information processing.

3.6 Modeling the effect of backpack weight on working memory task performance distribution

For each experiment task, a quantitative model was developed to predict the effect of backpack weight on WM task performance distribution. The model was developed using binary logistic regression where the independent variables were the BW level and WM task score threshold. The model predicts the probability that an individual's WM task score is larger than a given threshold according to the BW level.

3.6.1 Standing task

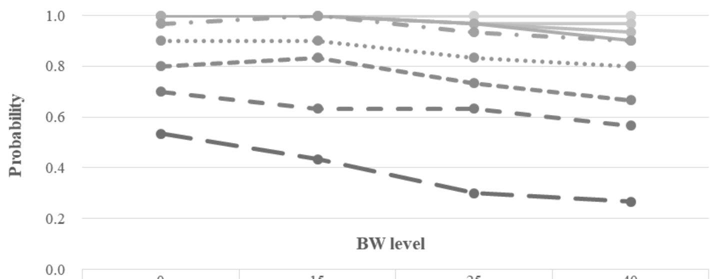
Figures 3.21a-3.21c visually depict the relationship between the percentage of individuals meeting a given minimum WM task score and the BW level for the three experiment tasks (the V-S, P-S and C-S tasks). For the V-S and C-S tasks, logistic regression models were developed to quantitatively model the relationships.



	0	15	25	40
WM Score > 0	1.00	1.00	1.00	0.93
WM Score > 1	1.00	0.93	1.00	0.93
WM Score > 2	1.00	0.90	0.87	0.90
WM Score > 3	0.93	0.80	0.63	0.77
WM Score > 4	0.90	0.63	0.53	0.57

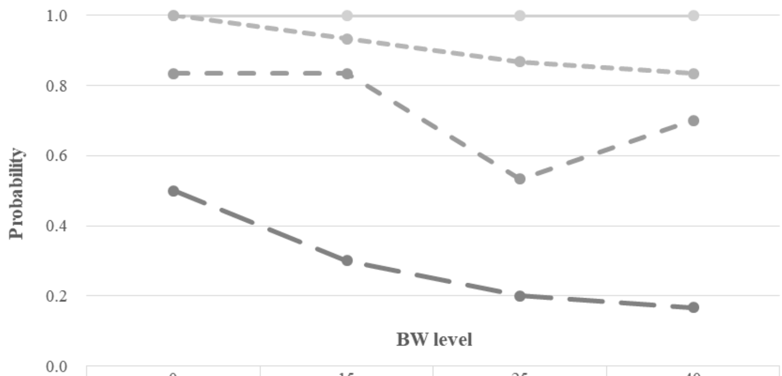
Logistic regression model	Percentage correct	Hosmer & Lemeshow	X_1	X_2
$p = 1/(1+e^{-(5.008-0.038X_1-0.905X_2)})$	85.5	0.455	BW level	Threshold

(a) V-S task



BW level	0	15	25	40
WM Score > 0	1.00	1.00	1.00	1.00
WM Score > 1	1.00	1.00	1.00	1.00
WM Score > 2	1.00	1.00	0.97	0.97
WM Score > 3	1.00	1.00	0.97	0.93
WM Score > 4	1.00	1.00	0.97	0.90
WM Score > 5	0.97	1.00	0.93	0.90
WM Score > 6	0.90	0.90	0.83	0.80
WM Score > 7	0.80	0.83	0.73	0.67
WM Score > 8	0.70	0.63	0.63	0.57
WM Score > 9	0.53	0.43	0.30	0.27

(b) P-S task



BW level	0	15	25	40
WM Score > 0	1.00	1.00	1.00	1.00
WM Score > 1	1.00	0.93	0.87	0.83
WM Score > 2	0.83	0.83	0.53	0.70
WM Score > 3	0.50	0.30	0.20	0.17

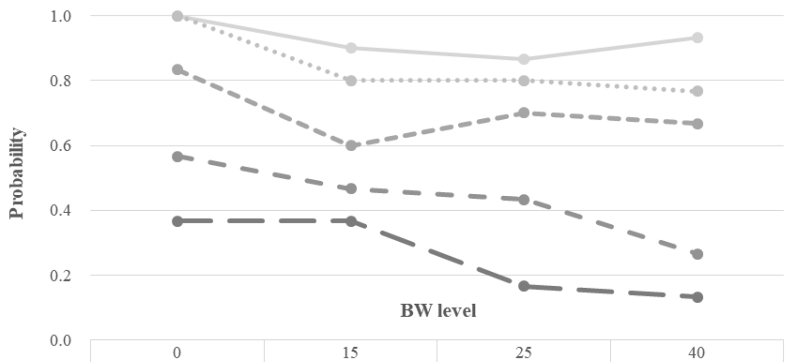
Logistic regression model	Percentage correct	Hosmer & Lemeshow	X_1	X_2
$p = 1/(1+e^{-(5.408-0.038X_1-1.859X_2)})$	83.5	0.632	BW level	Threshold

(c) C-S task

Figure 3.21 Effect of backpack weight on WM task performance distribution

3.6.2 Navigating task

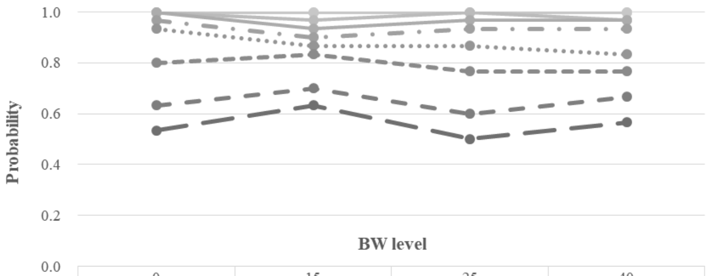
Figures 3.22a-3.22c visually depict the relationship between the percentage of individuals meeting a given minimum WM task score and the BW level for the three experiment tasks (the V-N, P-N and C-N tasks). For the V-N and C-N tasks, logistic regression models were developed to quantitatively model the relationships.



	0	15	25	40
WM Score > 0	1.00	0.90	0.87	0.93
WM Score > 1	1.00	0.80	0.80	0.77
WM Score > 2	0.83	0.60	0.70	0.67
WM Score > 3	0.57	0.47	0.43	0.27
WM Score > 4	0.37	0.37	0.17	0.13

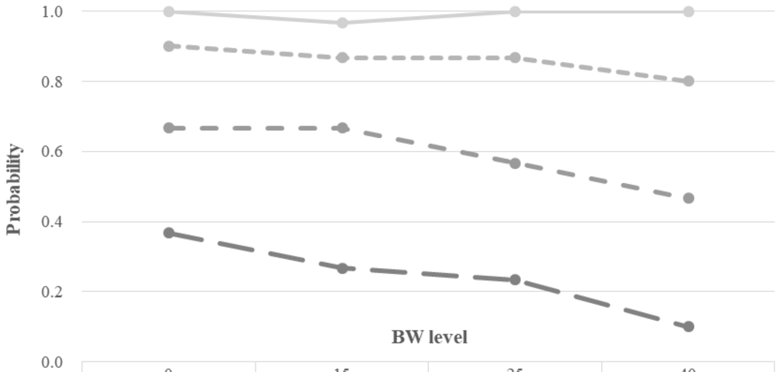
Logistic regression model	Percentage correct	Hosmer & Lemeshow	X_1	X_2
$p = 1/(1+e^{-(3.272-0.030X_1-0.954X_2)})$	76.2	0.969	BW level	Threshold

(a) V-N task



	0	15	25	40
WM Score > 0	1.00	1.00	1.00	1.00
WM Score > 1	1.00	1.00	1.00	1.00
WM Score > 2	1.00	1.00	1.00	1.00
WM Score > 3	1.00	0.97	1.00	0.97
WM Score > 4	1.00	0.93	0.97	0.97
WM Score > 5	0.97	0.90	0.93	0.93
WM Score > 6	0.93	0.87	0.87	0.83
WM Score > 7	0.80	0.83	0.77	0.77
WM Score > 8	0.63	0.70	0.60	0.67
WM Score > 9	0.53	0.63	0.50	0.57

(b) P-N task



	0	15	25	40
WM Score > 0	1.00	0.97	1.00	1.00
WM Score > 1	0.90	0.87	0.87	0.80
WM Score > 2	0.67	0.67	0.57	0.47
WM Score > 3	0.37	0.27	0.23	0.10

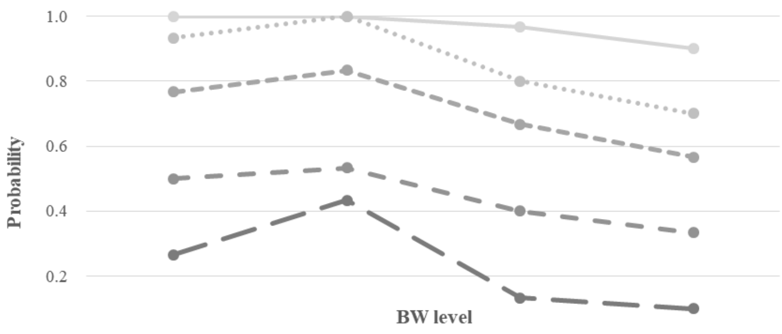
Logistic regression model	Percentage correct	Hosmer & Lemeshow	X_1	X_2
$p = 1/(1+e^{-(4.232-0.026X_1-1.652X_2)})$	80.4	0.781	BW level	Threshold

(c) C-N task

Figure 3.22 Effect of backpack weight on WM task performance distribution

3.6.3 Walking task

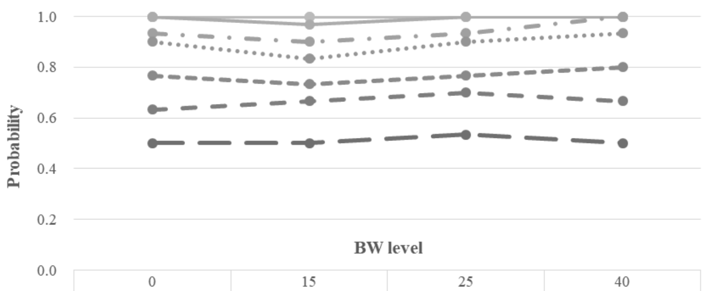
Figures 3.23a-3.23c visually depict the relationship between the percentage of individuals meeting a given minimum WM task score and the BW level for the three experiment tasks (the V-W, P-W and C-W tasks). For the V-W and C-W tasks, logistic regression models were developed to quantitatively model the relationships.



	0	15	25	40
WM Score > 0	1.00	1.00	0.97	0.90
WM Score > 1	0.93	1.00	0.80	0.70
WM Score > 2	0.77	0.83	0.67	0.57
WM Score > 3	0.50	0.53	0.40	0.33
WM Score > 4	0.27	0.43	0.13	0.10

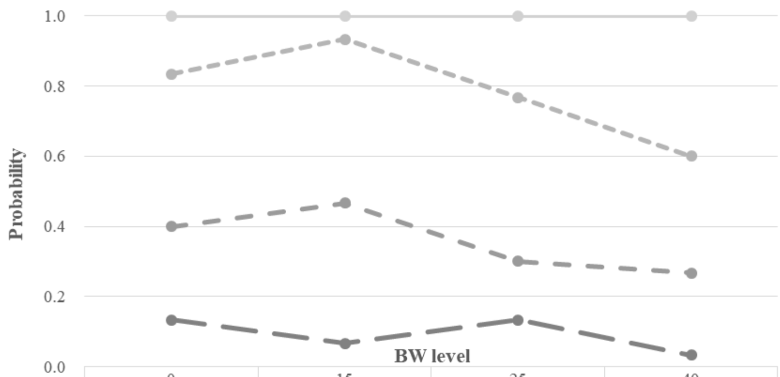
Logistic regression model	Percentage correct	Hosmer & Lemeshow	X_1	X_2
$p = 1/(1 + e^{-(3.811 - 0.034X_1 - 1.113X_2)})$	77.2	0.191	BW level	Threshold

(a) V-W task



	0	15	25	40
WM Score > 0	1.00	1.00	1.00	1.00
WM Score > 1	1.00	1.00	1.00	1.00
WM Score > 2	1.00	1.00	1.00	1.00
WM Score > 3	1.00	1.00	1.00	1.00
WM Score > 4	1.00	0.97	1.00	1.00
WM Score > 5	0.93	0.90	0.93	1.00
WM Score > 6	0.90	0.83	0.90	0.93
WM Score > 7	0.77	0.73	0.77	0.80
WM Score > 8	0.63	0.67	0.70	0.67
WM Score > 9	0.50	0.50	0.53	0.50

(b) P-W task



	0	15	25	40
WM Score > 0	1.00	1.00	1.00	1.00
WM Score > 1	0.83	0.93	0.77	0.60
WM Score > 2	0.40	0.47	0.30	0.27
WM Score > 3	0.13	0.07	0.13	0.03

Logistic regression model	Percentage correct	Hosmer & Lemeshow	X_1	X_2
$p = 1/(1 + e^{-(4.183 - 0.027X_1 - 2.092X_2)})$	83.3	0.271	BW level	Threshold

(c) C-W task

Figure 3.23 Effect of backpack weight on WM task performance distribution

3.6.4 Discussion

The objective of the analyses conducted in this section was to quantitatively model the effect of backpack weight on WM task performance distribution for the nine experiment tasks. For each experiment task, a logistic regression model was developed, which predicts the percentage of individuals accomplishing a certain minimum WM task score (Figures 3.21-3.23). No significant regression model was derived for the P-S, P-N and P-W tasks. The logistic regression models generally showed high prediction accuracy (average of 81%). The models could be used to perform sensitivity analyses for examining the effects of the BW level changes. This might help designers make decisions on the body-worn equipment weight although further research studies are needed to realize that.

In order to utilize the model for design decision making, a certain design goal/constraint must be expressed as a condition on the percentage of individuals who accomplish a minimum WM task score. For example, to solve the design problem that determines the acceptable weight of military gear, the target percentage of individuals who accomplish a certain minimum WM task score must be predetermined. To do so, the relationship between the basic WM scores and some meaningful real-world task performance measures need to be established – such relationship could be utilized to translate the design goal in terms of the real-world task performance measures into that in the basic WM task scores. Further studies on the relationship between real-world mental task performance and WM task performance are needed to provide more specific and well-defined design guidelines using the models developed in this study.

Chapter 4. Postural loading and working memory task performance

4.1 Background

In many industrial fields, workers perform their tasks with various working postures. For example, workers in manufacturing industries are needed to execute various working postures such as reaching, stooping and twisting. These situations result in physical workload related to the working postures, and as a result, may have a negative impact on performance on the field. Existing works in the occupational biomechanics and physical ergonomics fields state that an inappropriate working posture causes excessive postural loading, discomfort and pain, and an increase in WMSD risks, and a decrease in productivity of physical work (Aarås, Westgaard, and Stranden 1988; Alexopoulos, Burdorf, and Kalokerinou 2003; Armstrong et al. 1993; Burdorf, Govaert, and Elders 1991; Choobineh et al. 2007; Gangopadhyay et al. 2010; Grandjean and Honting 1977; Silverstein, Fine, and Armstrong 1987; Tinubu et al. 2010; Valachi and Valachi 2003).

The occupational activities of these workers are not limited to physical tasks. They also perform various mental tasks along with physical ones – the mental and physical tasks are conducted close in time and often simultaneously. For example, workers in the medical field such as doctors, nurses, and pharmacists frequently multitask and are faced with high level of mental workload in addition to physical workload (Aminian, Alemohammad, and Sadeghniiat-Haghighi 2012; Barker and Nussbaum 2011; Beynon and Reilly 2001; Page 2004; Ryu et al. 2014; Soh and Crumpton 1996; Trinkoff, Storr, and Lipscomb 2001; Wolf et al. 2006). Nurses are required to complete physical tasks such as lifting patients for transfer out of bed and from the floor, while completing mental tasks, all in an urgent and busy work environment. Doctors are also faced with tasks with a high-level of mental workload such as consultation and surgery, while in awkward postures such as leaning the neck and body in one direction while the upper body is bent forwards. Also, control tower workers, airplane pilots and locomotive pilots are required to execute various postures for tasks such as machine or control operation in addition to completing high-level mental tasks.

The previous results on the inter-relationship between the concurrent physical and mental tasks as mentioned in Section 1.1, lead to the hypothesis that the postural loading caused by working posture affects the performance of some of their mental tasks. Understanding how the postural loading affects the performance of different mental tasks will provide a basis for designing work tasks to maximize performance and worker wellbeing. Additionally, understanding such a phenomenon may aid in the design of a safe system that may prevent the loss of lives and property damage.

In spite of the importance of the abovementioned knowledge, the relationship between postural loading and mental task performance is still not well known. Existing research on the relationship between postural loading and mental task performance either only dealt with a very small number of postures in a specific work task environment (Deaton and Hitchcock 1991; Drury et al. 2008; Liao and Drury 2000; Thomas et al. 1991), or focused on postural control for balance maintenance (Dault, Frank, and Allard 2001; Kerr, Condon, and McDonald 1985; Yardley et al. 2001). There seemed to be little to no research on the effect of postural loading on mental task performance in regards to industrial working postures.

4.2 Overview

This chapter aimed to empirically investigate the effects of postural loading on a worker's performance of basic WM tasks.

Especially, industrial working postures with a large postural loading variation were chosen. A specific posture was held for a predetermined amount of time, and four posture groups (a total of 12 postures) were considered, each with a different amount of postural loading.

Three types of WM tasks (visuo-spatial component, phonological loop and central executive systems) were considered based on the Baddeley's WM model (Baddeley 1983). Therefore, the current study examined the postural loading effects on WM task performance for each of the three subcomponents of WM, separately.

Other variables (behavioural, physiological, and psychophysical measures) that would be helpful in understanding the effect of postural loading on WM task performance were also considered.

4.3 Method

4.3.1 Participants

Thirty participants (15 males and 15 females) in their 20s and 30s participated in the experiment. Participants were free of musculoskeletal and neurological disorders. All participants signed an informed consent form prior to participation. The data collection protocol had been approved by the Institutional Review Board of Seoul National University.

4.3.2 Experimental tasks

In this experiment, the participants conducted three experiment tasks each of which consisted of a physical and a WM task simultaneously performed.

The physical task consisted of holding various working postures with different postural loading for one minute, and this was consistent for the three experiment tasks. Postural loading was the independent variable of the study and had four levels. Four posture groups with different postural loadings (Figure 4.1) were based on the four operative classes (Table 4.1) of OWAS (Karhu, Kansi, and Kuorinka 1977), which is an assessment method widely used in the field of ergonomics for assessing working posture discomfort. Posture groups 1-4 consist of postures that correspond to OWAS operative classes 1-4. Each posture group consists of three postures of the same operative class, for a total of twelve postures (12 = 4 posture groups $\times$ 3 postures), shown in Figure 4.1. The base of support (BoS) for all postures was consistent.

Table 4.1. Operative classes of OWAS

Class	Explanation
1	Normal postures which do not need any special attention, except in some special cases
2	Postures must be considered during the next regular check of working methods
3	Posture need consideration in the near future
4	Postures need immediate consideration

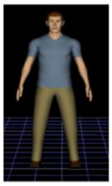
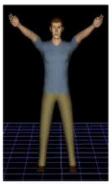
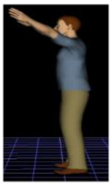
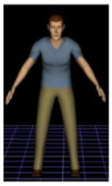
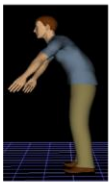
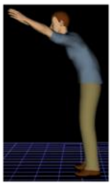
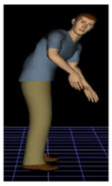
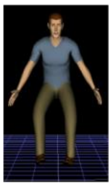
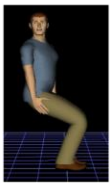
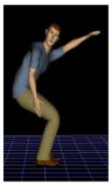
Group number	OWAS class	Posture number					
		1		2		3	
		Front view	Side view	Front view	Side view	Front view	Side view
1	1						
2	2						
3	3						
4	4						

Figure 4.1 Posture group

As in Chapter 3, different types of WM tasks were presented for the three experiment tasks. They were the Corsi block task (Corsi 1972), digit span task (Wechsler 1939), and 3-back task (Kirchner 1958). They corresponded to the three components of the Baddeley's WM model (the visuo-spatial sketchpad, phonological loop and central executive systems).

The three experiment tasks, each of which required simultaneously performing the postural holding task and one of the WM tasks, were named as the V-P (visuo-spatial WM task and postural holding), P-P (phonological loop WM task and postural holding) and C-P (central executive WM task and postural holding) tasks, respectively.

4.3.3 Procedures and dependent measures

In this study, each participant performed 36 experiment trials (36 = 4 postural loading levels × 3 postures × 3 experiment tasks). The order of the 36 trials was randomized for each participant. To minimize the effect of fatigue, each participant conducted the 36 trials over a period of six days and plenty of time for rest (minimum of 30 minutes) was given between trials. The minimum rest time of 30 minutes was determined based on existing research on muscle fatigue and recovery (Barbonis 1978; Jones and Ruiter 2006; Miller et al. 1987; Milner, Corlett, and O'Brien 1986). Prior to the experiment trials, an introduction/training session had been provided to the participants to allow for familiarization with the experimental tasks.

The procedure for the V-P task was as follows: at the beginning of a task trial, the participant stood on top of a Bertec force plate (model 4060, Bertec Corporation, Columbus, USA) and was presented one randomly selected posture through a 27-inch monitor, which is placed in front of the participant. The presented posture was held for 1 minute. As soon as the postural holding task finished, the participant was presented with the Corsi block task, in the form of visual stimuli on the monitor. Afterwards, an additional 15 seconds of the postural holding task resumed as soon as the visual stimuli presentation ended. The postural holding time of 15 seconds (time duration for participant's visual information retention) was based on the knowledge that short-term memory holding time is generally known as 10-15 seconds

(Campbell and Bagshaw 2008; Goldstein 2014). Immediately after the 15 seconds time interval, the participant reproduced the sequence of black circles by pointing on the answer sheet presented on the monitor screen. The Corsi block task score was recorded.

The procedure for the P-P task was as follows: at the beginning of a task trial, the participant stood on the force plate and was presented a specific posture for the specific trial through a 27-inch monitor, which is placed in front of the participant. The presented posture was held for 1 minute. Second, as soon as the postural holding task ended, the participant was presented with auditory stimuli (ten numbers) according to the protocol of the digit span task. As the auditory stimuli presentation ended, an additional 15 seconds of the postural holding task was resumed. Immediately after the 15 seconds time interval, the participant reproduced the auditory stimuli by speaking. The digit span task score was recorded.

The procedure for the C-P Task is as follows: at the beginning of a trial, the participant stood on the force plate and was presented a specific posture for the specific trial through a 27-inch monitor, which is placed in front of the participant. After holding the presented posture for 1 minute, the participant was presented with the target number for the 3-back task. Then, the participant performed the 3-back task and postural holding task simultaneously. The participant was instructed to verbally respond immediately when the target number was presented. The 3-back task score was recorded.

For all three experiment tasks, behavioural, physiological, and psychophysical response data, which were thought to be helpful in understanding the effects of postural holding on WM task performance, were collected from the participants during or after each task trial. Postural sway data were obtained using the force plate recordings of the CoP position-time profile during the 15 seconds of the postural holding task. The sampling frequency of the force plate was 100Hz. Among various postural sway measures, sway area, sway path and sway maximal amplitude were employed in this study as they had been widely utilized in research studies (Albright and Woodhull-Smith 2009; Diener et al. 1984; Kerr, Condon, and McDonald 1985; Maylor, Allison, and Wing 2001; Panjan and Sarabon 2010; Rode, Tiliket, and Boisson 1997; Shumway-Cook and Woollacott 2000; Thapa et al. 1996). The three postural sway measures were described in Table 4.2. Sway area was calculated using the area of convex hull which is defined as the smallest polygon in which no internal angle exceeds 180 degrees and contains all sites of occurrence. The vertices of convex hull polygon were computed using the gift wrapping algorithm (Wollseifen 2011). The medio-lateral (ML) and anterior-posterior (AP) directions were considered for the sway maximal amplitude.

Table 4.2 Postural sway measures

Measure	Unit	Description
Sway area	mm^2	The time integral of the area swept by the CoP trajectory with respect to platform center
Sway path	mm	The length of the trajectory of the CoP sway
Sway maximal amplitude	mm	The amplitude between the two most distant samples of CoP sway (ML/AP)

Heart rate was measured right after each task trial using Samsung gear fit 2. Additionally, each participant conducted subjective ratings of physical discomfort and mental workload immediately after each task trial. The Borg CR10 scale (Borg 1982) was employed.

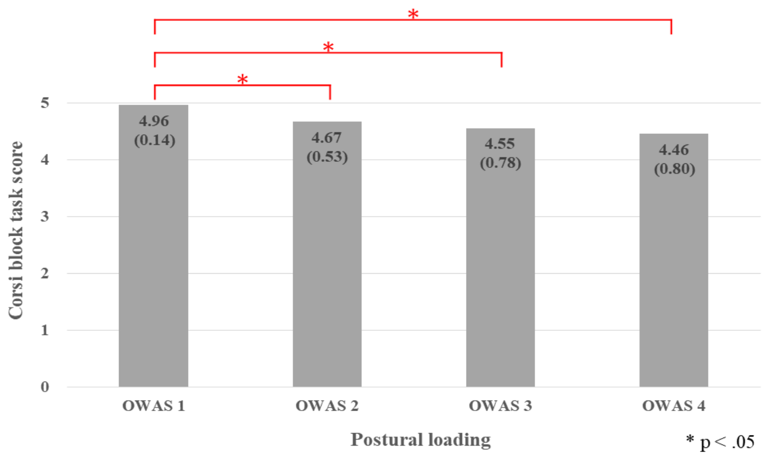
4.3.4 Data analyses

For each of the three experiment tasks, one-way repeated measures ANOVA was conducted to test the effect of postural loading on the corresponding WM task score and other dependent measures (behavioural, physiological, and psychophysical measures). The average score of the three postures for each posture group was calculated, and used for statistical analysis. Mauchly's test was performed to assess the sphericity of data for each ANOVA. In cases where sphericity was violated, the degrees of freedom were corrected – the Greenhouse-Geisser correction was used when the Greenhouse-Geisser estimate of sphericity (ε) was less than 0.75; otherwise, the Huynh-Feldt correction was used (Field 2009). In the case of significant ANOVA results, post-hoc Bonferroni multiple pairwise comparisons were conducted. Bonferroni corrections were made. All statistical tests were conducted using IBM SPSS Statistics 23.0, and were based on an alpha level of 0.05.

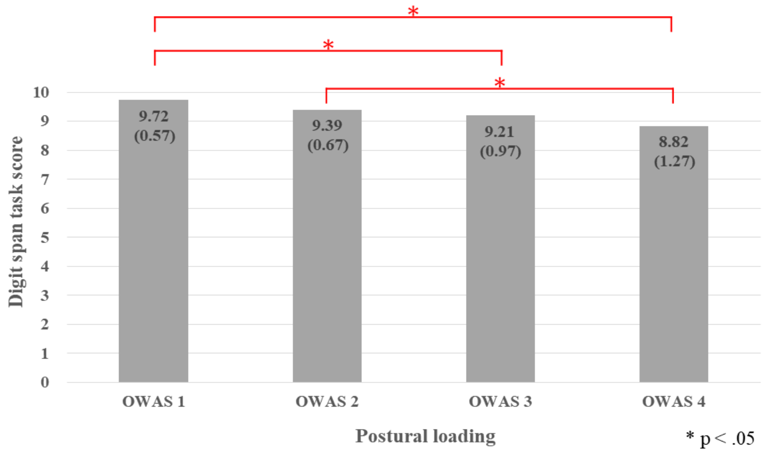
4.4 Results

4.4.1 Working memory task scores

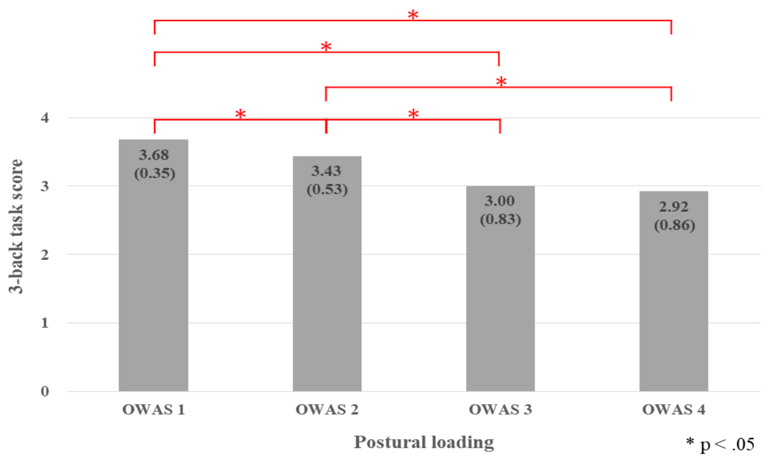
The ANOVAs revealed that postural loading significantly affected all of the three WM task scores (F=6.414, 10.171 and 24.828 for the V-P, P-P and C-P tasks, respectively, p<.05). For all of the three experiment tasks (the V-P, P-P and C-P tasks), WM task performance decreased as postural loading increased. The effect of postural loading on WM task performance was more pronounced for the C-P task than the V-P and P-P tasks. Figure 4.2 visually depicts the effects of postural loading. In each figure, the mean and standard deviation of the WM task scores are presented for each level of postural loading. The asterisks indicate statistically significant differences detected by the post hoc Bonferroni multiple pairwise comparisons.



(a) V-P task



(b) P-P task

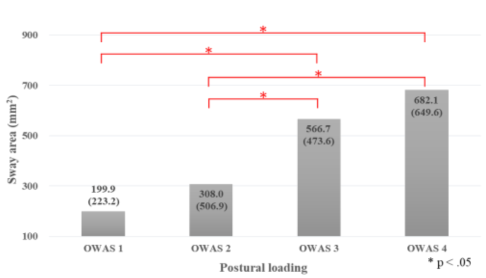


(c) C-P task

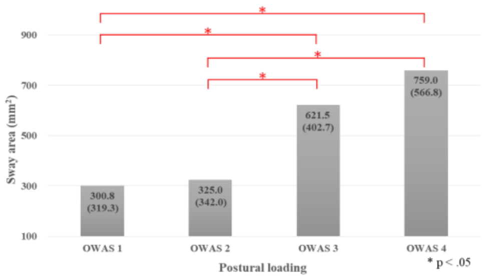
Figure 4.2 Effects of postural loading on WM task scores

4.4.2 Postural sway measures

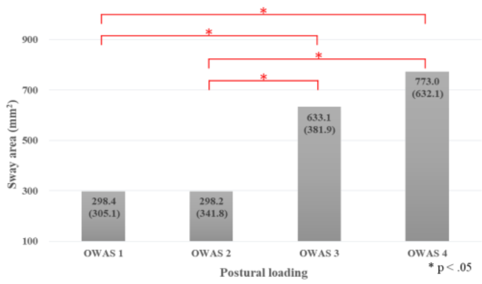
The ANOVAs indicated that postural loading significantly affected all three postural sway measures for each of the three experiment tasks (F=17.989, 20.327 and 19.029 for the V-P, P-P and C-P tasks, respectively, $p<.05$). As postural loading increased, all of the three postural sway measures increased. The value for the postural sway was distinctly larger for posture groups 3 and 4 in comparison to posture groups 1 and 2. Figures 4.3-4.5 visually depict the effects of postural loading on the three postural sway measures (sway area, sway path and sway maximal amplitude), respectively. For the sway maximal amplitude measure, observations in regards to the medio-lateral (ML) and anterior-posterior (AP) directions were presented.



(a) V-P task

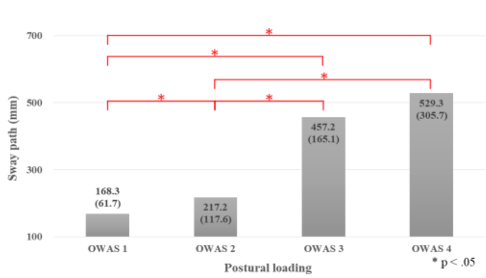


(b) P-P task

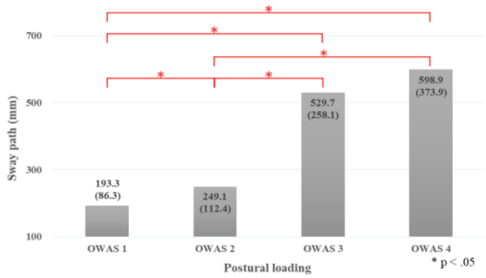


(c) C-P task

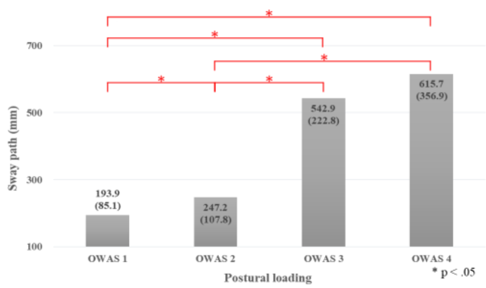
Figure 4.3 Effects of postural loading on sway area



(a) V-P task

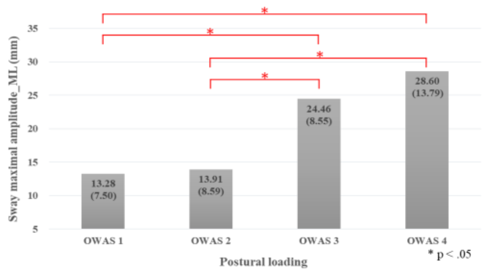


(b) P-P task

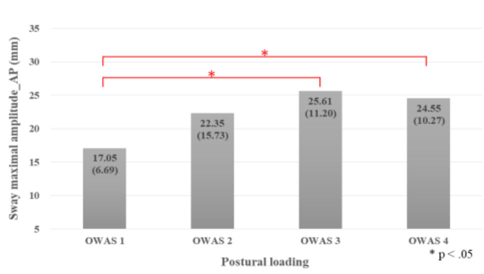


(c) C-P task

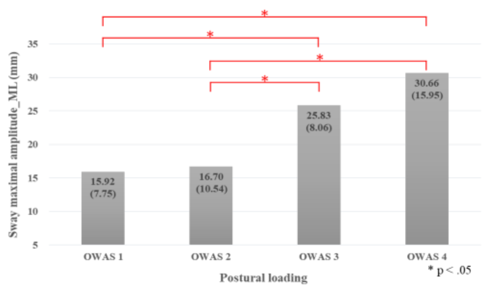
Figure 4.4 Effects of postural loading on sway path



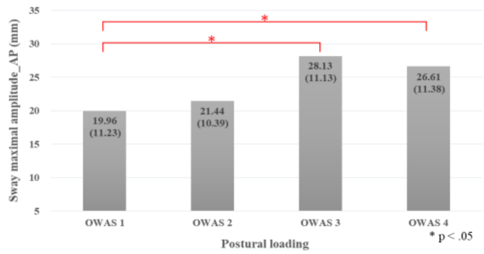
(a) V-P task (ML)



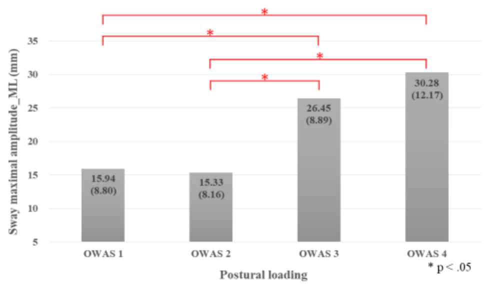
(b) V-P task (AP)



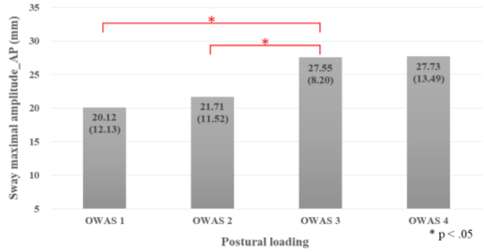
(c) P-P task (ML)



(d) P-P task (AP)



(e) C-P task (ML)



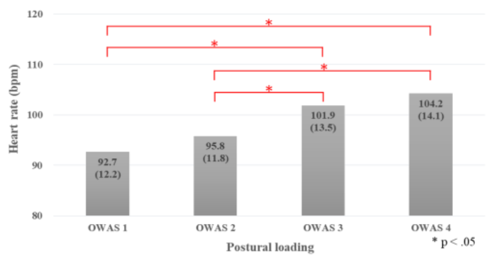
(f) C-P task (AP)

Figure 4.5 Effects of postural loading on sway maximal amplitude

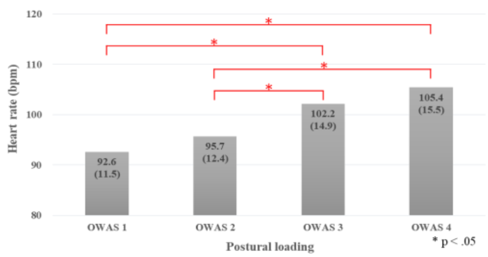
*** note: medio-lateral direction (ML), anterior-posterior direction (AP)**

4.4.3 Heart rate

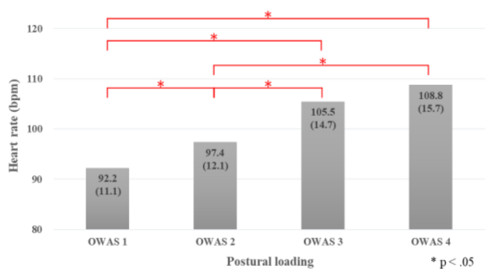
The ANOVA found that postural loading significantly affected heart rate in all three experiment tasks (F=37.315, 31.037 and 49.392 for the V-P, P-P and C-P tasks, respectively, $p<.05$). As postural loading increased, heart rate increased for all of the three experiment tasks. Figure 4.6 visually depicts the postural loading effects.



(a) V-P task



(b) P-P task

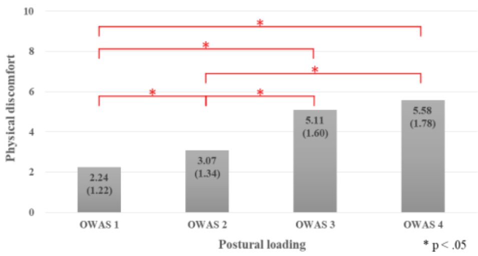


(c) C-P task

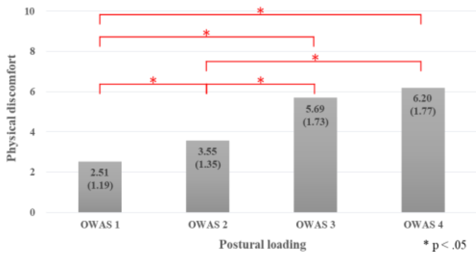
Figure 4.6 Effects of postural loading on heart rate

4.4.4 Physical discomfort and mental workload

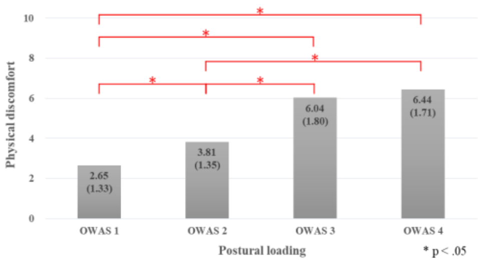
The ANOA results indicated that postural loading significantly affected both the physical discomfort and mental workload ratings for all three experimental tasks (F=98.343, 110.803 and 129.049 for the V-P, P-P and C-P tasks, respectively, p<.05). As postural loading increased, physical discomfort and mental workload ratings increased for all of the three experiment tasks. Figures 4.7-4.8 visually depict the effects of postural loading.



(a) V-P task

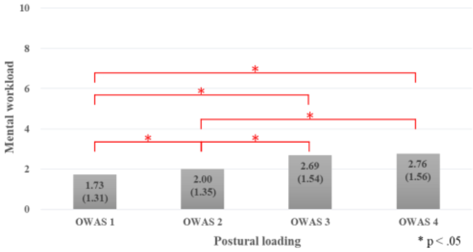


(b) P-P task

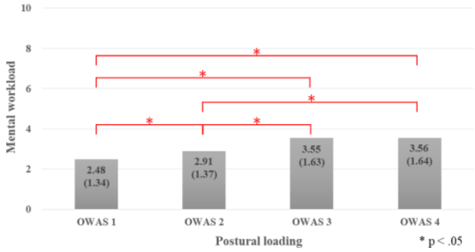


(c) C-P task

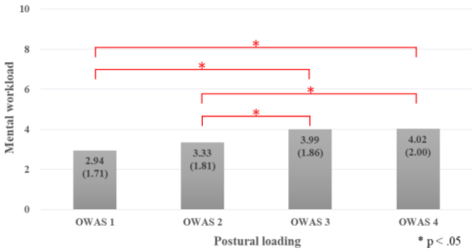
Figure 4.7 Effects of postural loading on physical discomfort



(a) V-P task



(b) P-P task



(c) C-P task

Figure 4.8 Effects of postural loading on mental workload

4.5 Discussion

The objective of the current study was to empirically investigate the effects of postural loading on a worker's performance of basic WM tasks. In the case of the physical task, a specific posture was held for one minute, and four posture groups (a total of 12 postures) were considered, each with a different amount of postural loading. Three WM tasks, that is, the Corsi block, digit span and 3-back tasks, were considered so as to examine the different sub-components of the WM system, that is, the visuo-spatial sketchpad, phonological loop and central executive systems. The scores of the three WM tasks and a set of measures pertinent to postural sway, heart rate, physical discomfort and perceived mental workload were employed as the dependent variables of the study. Statistical analyses were conducted to test the effects of postural loading on the dependent variables.

The data analyses revealed significant effects of postural loading on the scores of the WM tasks and also the other dependent variables. For all of the three experiment tasks (the V-P, P-P and C-P tasks), WM task performance decreased as postural loading increased (Figure 4.2). Also, as postural loading increased, all of the three postural sway measures, and the heart rate, physical discomfort rating, and mental workload rating increased (Figures 4.3-4.8).

The observed postural loading effects on WM task performance (Figure

4.2), that is, decreases in WM task performance resulting from increased postural loading, could be explained largely in terms of the limited attentional resources of the human information processing system.

As mentioned in section 3.5, a human operator has a limited capacity of attention resources (Broadbent 2013; Kahneman 1973; Pashler and Sutherland 1998; Treisman 1960; Wickens et al. 2013). If the total attention demand of the concurrent tasks exceeds the human capacity, the performance of one or more of these tasks will suffer (Wickens et al. 2013). In this study, each experiment trial required the participants to simultaneously perform a postural holding task and a WM task. The postural holding task required both response monitoring to compare his/her own posture with a presented posture, and postural control to maintain body balance which is accomplished through feedback control (compensatory reactive postural responses) (Shumway-Cook and Woollacott 2007). Such postural control requires attentional resources (Kerr, Condon, and McDonald 1985; Lajoie et al. 1993, 1996; Shumway-Cook et al. 1997; Teasdale et al. 1993). Also, each of the three WM tasks employed in this study demands attentional resources as it requires the participants to perceive information in the environment and maintain it through rehearsal (Wickens et al. 2013). It is thought that in each of the three experiment tasks, increased postural loading increased the difficulty of the postural holding task, and, therefore, increased the amount of attention allocated to it, and this further resulted in the shortage of available resources for the concurrent WM task and eventually its performance decrease. The increases in the three postural sway measures associated with increased postural loading, shown in Figures 4.3-4.5, seem to depict the impact of postural loading on the difficulty of the postural holding task. Also, the increases in perceived mental workload associated with increased postural loading, shown in Figure 4.8, are thought to reflect the progressive reduction of attentional resources available for the WM tasks resulting from postural loading increases.

The observed postural loading effects on the performance of the WM tasks (Figure 4.2) could also be explained on the basis of the neural mechanisms underlying different physical and mental tasks. From the neuroscience point of view, two tasks performed simultaneously are considered interfering with each other when their individual patterns of brain activation have a significant overlap, in other words, when they utilize the very same population of neurons (Klingberg and Roland 1997; Klingberg 1998; Passingham 1996; Rémy et al. 2010; Roland and Zilles 1998; Wu, Kansaku, and Hallett 2004). This neuroscience view on between-task interference is similar to the idea that concurrent tasks interfere with one another when they compete for limited attentional resources.

This study presented three types of WM tasks to be completed simultaneously with a postural holding task as the physical task. According to existing neuroscience studies, postural holding activates the following brain areas: primary motor cortex, DLPFC, midline cerebellum (vermal/paravermal cerebellum), posterior parietal cortex, SMA, PMC, occipital area (primary visual cortex), FEF and pons (pontine nuclei) (Ashe et al. 2006; Chambers and Sprague 1955; Courville 1966; de Lange, Helmich, and Toni 2006; Flumerfelt, Otabe, and Courville 1973; la Fougère et al. 2010; Luft et al. 2002; Mihara et al. 2008; Mihara et al. 2012; Ouchi et al. 1999; Roland et al. 1980; Shibasaki et al. 1993; Wang et al. 2008; Wittenberg et al. 2017).

Visuo-spatial WM tasks have been reported to activate the VLPFC, posterior parietal cortex, PMC, occipital area, and ACC (Awh, Jonides, and Smith 1996; Awh and Jonides 1998; Cohen et al. 1997; Courtney et al. 1997; Fiez et al. 1996; Gluck, Mercado, and Myers 2013; Haxby, Grady, and Horwitz 1991; Kammer et al. 1997; Klingberg 1998; Na et al. 2000; Salmon et al. 1996; Ungerleider 1995). Hence, the postural holding and visuo-spatial WM tasks of the V-P task of the current study have an overlap of brain activation in the posterior parietal cortex, PMC, and occipital area, and, thus, can be thought of as interfering with each other.

Phonological loop WM tasks were reported to activate the following areas: VLPFC, primary auditory cortex, PMC, SMA, Broca’s area, posterior parietal cortex, ACC, and posterior-lateral cerebellum (Awh, Jonides, and Smith 1996; Awh and Jonides 1998; Cohen et al. 1997; Courtney et al. 1997; Fiez et al. 1996; Gluck, Mercado, and Myers 2013; Hertrich, Dietrich, and Ackermann 2016; Kammer et al. 1997; Klingberg 1998; Meister et al. 2007; Na et al. 2000; Paulesu, Frith, and Frackowiak 1993; Salmon et al. 1996;

Smith et al. 1998; Watkins and Paus 2004; Wilson and Iacoboni 2006). Thus, the postural holding and phonological loop WM tasks of the P-P task of the current study can be regarded as interfering with each other as they have an overlap of brain activation in the PMC, posterior parietal cortex, and SMA.

Central executive WM tasks are known to activate the DLPFC, VLPFC, primary auditory cortex, PMC, SMA, posterior parietal cortex, posterior-lateral cerebellum, ACC, and thalamus (Courtney et al. 1997; Gluck, Mercado, and Myers 2013; Henson, Shallice, and Dolan 1999; Jonides et al. 1993; Klingberg 1998; Na et al. 2000; Nyberg, Cabeza, and Tulving 1996; Owen 2000; Owen et al. 2005; Wagner et al. 1998; Wagner et al. 1998). Therefore, the postural holding and central executive WM tasks of the C-P task of the current study have an overlap of brain activation in the DLPFC, PMC, posterior parietal cortex, and SMA, and, thus, can be thought of as interfering with each other.

As described above, each of the three experiment tasks (the V-P, P-P and C-P tasks) is subject to dual-task interference as the postural holding and WM tasks constituting it have a significant overlap of neural activation in brain areas. As postural loading increases, the amount of neuronal resources used by the postural holding task would increase leading to increased dual task interference and thus decreased WM task performance.

The observed effects of postural loading on WM task performance

(Figure 4.2) may also be attributed to the impacts of negative emotional experience on human information processing. The detailed description is the same as in section 3.5. In the current study, perceived physical discomfort was found to increase as postural loading increased (Figure 4.7). Also, heart rate increased as postural loading increased indicating an increase in physical and mental workload (Figure 4.6). These changes associated with increased postural loading may have caused increases in negative emotions, have caused narrowing of attentional scope, and have further disrupted the WM tasks.

The above accounts of the study findings on the basis of the impacts of negative emotional experience are further supported by the neural mechanism of discomfort/pain perception. The detailed descriptions related to this process are same as mentioned in section 3.5. The muscle pain increases as postural loading increases, and such a neural mechanism that carries out pain perception may act as interference in completing a WM task.

An interesting observation from the current study results was that the effect of postural loading on WM task performance was more pronounced for the C-P task than the V-P and P-P tasks (Figures 4.2a-4.2c) – the C-P task showed 21% reduction in the mean WM task score as the postural loading increased from OWAS 1 to OWAS 4; on the other hand, the V-P and P-P tasks showed 10% and 9% reductions associated with the increase in the postural loading. This phenomenon may be explained by the threaded cognition theory (Salvucci and Taatgen 2008), which explains information processing in terms of within-resource seriality and between-resource parallelism. This theory states that two tasks can be conducted simultaneously when separate resources are used, but in the case when a particular resource is required in both tasks, tasks are conducted serially resulting in the reduction of task performance. In completing the postural holding task used in this study, it can be said that the central executive resource is mainly required in regards to volition (the capacity for intentional behavior and for initiation of activity), response monitoring (compare ongoing actions with an internal plan and to detect errors), and allocating attention (Yogev-Seligmann, Hausdorff, and Giladi 2008). Therefore, the same resource is required when completing the postural holding task and central executive WM task; this may have caused a larger dual-task interference.

This study collected the body balance data of the participants during the postural holding and WM tasks, and it was observed that all three postural sway measures showed a tendency to increase as postural loading increased (Figures 4.3-4.5). An important observation was that the value for the postural sway was distinctly larger for posture groups 3 and 4 (corresponding to OWAS classes 3 and 4, respectively) in comparison to posture groups 1 and 2 (corresponding to OWAS classes 1 and 2, respectively). The results may be explained due to the increased physical discomfort as a result of increased postural loading, but further analysis of the postures that make up each posture group resulted in a more plausible explanation. That is, the postures that compose posture groups 1 and 2 seem to have minimal knee flexion. On the other hand, posture groups 3 and 4 consist of postures with larger knee flexion angles, such as the squat posture. Therefore, holding the postures in posture groups 3 and 4 results in the centre of gravity (CoG) reaching the limits of base of support (stability limits), resulting in an increased difficulty in maintaining body balance. This interpretation may explain the reason for a higher postural sway for posture groups 3 and 4, compared to that of posture groups 1 and 2. Another important observation was that the collected postural sway data had a similar pattern to the central executive WM task score. In other words, posture groups 3 and 4 showed a significantly lower score distribution than posture groups 1 and 2 in regards to central executive WM task score; post-hoc comparison results were statistically significant. In contrast, the scores for the visuo-spatial and phonological loop WM tasks did not show a similar pattern. On the basis of these results, it can be inferred that maintaining body balance mainly requires the central executive resource, and this inference is in accordance with results from existing studies (Shumway-Cook and Woollacott 2007; Van Iersel et al. 2008).

Chapter 5. Conclusion

5.1 Summary

The objective of the current study was to empirically investigate the effects of backpack weight (body-worn equipment weight) or postural loading on a worker's performance of basic WM tasks while simultaneously performing a certain physical task. The dissertation consisted of two major studies in relation to the research objectives.

In study 1, the effects of body-worn equipment weight on the performance of basic WM tasks were examined. Backpack weight had four levels (0, 15, 25 and 40% of the worker's body weight). Three types of physical tasks were considered in this study. They were the standing, navigating and walking tasks. Also, three WM tasks, that is, the Corsi block, digit span and 3-back tasks, were considered so as to examine the different sub-components of the WM system, that is, the visuo-spatial sketchpad, phonological loop and central executive systems. The results of data analyses showed that backpack weight affected WM task scores differently in regards to the type of WM task and physical task.

In study 2, the effects of postural loading on the performance of basic WM tasks were examined. In the case of the physical task, a specific posture was held for one minute, and four posture groups (a total of 12 postures) were considered, each with a different amount of postural loading. Three types of WM tasks were considered as in study 1. The data analyses revealed significant effects of postural loading on the scores of the WM tasks. For all of the three experiment tasks (the V-P, P-P and C-P tasks), WM task performance decreased as postural loading increased.

5.2 Implications of the research

This study examined the effect of backpack weight or postural loading on WM task performance in situations where physical and mental tasks are presented simultaneously. These findings provide valuable information that fill in a knowledge gap not previously addressed by previous studies. The WM tasks considered in this study corresponded to the three sub-systems of WM in the Baddeley model (Baddeley 1983). WM and its sub-systems are fundamental to human information processing and play a central role in conducting various cognitive tasks (Wickens et al. 2013) and also are related to the occurrences of different types of human errors (Norman 1981; Reason 1990; Wickens et al. 2013). The current study findings, due to their fundamentality, may help understand and predict the impacts of body-worn weights or postural loading on the worker's mental task performance in a variety of situations.

In this study, the effects of backpack weight or postural loading on WM task performance were discussed from various viewpoints such as limited attentional resources, neural mechanisms, negative affects/emotions, discomfort/pain perception, attentional scope and multiple resource theory; this enabled an in-depth understanding of interference during human information processing in a multitasking situation that demands the completion of both physical and mental tasks.

The study findings entail that reducing the body-worn equipment weight or postural loading can positively impact the worker's mental task performance in addition to reducing the worker's bodily stresses and the risks of work-related musculoskeletal disorders. This is especially important for situations where workers perform critical mental tasks along with demanding physical tasks, as in the work activities of soldiers, firefighters, pilots and medical team. Such results may contribute to the practical design of products or systems which require multitasking, by providing an experimental basis about the increased mental performance when using such products (or reducing the decrease of mental performance). Such results also provide empirical evidence about possible improvements for work tasks where multitasking of physical and mental tasks occur; this may be in the form of work station design or work posture improvement. More research studies are needed to collect human performance data for a wide range of dual-task conditions and develop design guidelines based on them.

The study results also provide valuable information in minimizing the mental performance reduction caused by dual-task interference. This information may be used in the beginning stages of design for new technology or products. Additionally, these results may offer a guide in minimizing the dual task interference when using such products. For example, the results of this study may suggest the benefits of using the auditory channel for a wide range of physical tasks requiring visuo-spatial and/or central executive resources.

The current study considered the standing, navigating and walking task, which are representative physical tasks performed by various workers including soldiers and firefighters. Thus, it is expected that the results will be able to be applied to various industries where multitasking is required.

5.3 Limitations and future works

Some limitations of the current study are acknowledged along with future research ideas: first, in study 1, loaded backpack was utilized as a representation of body-worn equipment weight. Given the many ways in which equipment can be designed and attached to the worker's body, it seems necessary to examine how different design solutions affect mental performances during dual-task situations. In addition to external weight imposed on the human body, other parameters representing the demands of a physical task, such as required speed and accuracy of movement, complexity of movement, localized muscle fatigue, etc., may affect the performance of different mental tasks performed concurrently with a physical task. More basic studies are needed to further our understanding of the interaction between concurrent mental and physical tasks.

Second, in study 2, postural holding task for a certain amount of time was considered as physical task, thus possibly limiting the application of the findings to similar contexts. It would be also meaningful to differentiate the postural holding time or consider repetitive movements of a certain posture in future studies. Also, the study generated posture groups with different postural loadings based on the operative classes of OWAS; it may be enlightening to examine further results between postures in terms of familiarity to the participant, right-left symmetry of the postures, etc. Analysis of such results may result in a widened range of knowledge about this topic.

Third, the current study imposed body-worn equipment weight or postural loading only in the memory retention stage during the experiment task trials. Future studies may consider examining the effects of external weight or postural loading in other stages, including stimulus encoding and memory retrieval, in order to further enhance our understanding of the effects of external weight or postural loading.

Fourth, this study did not consider the physical performance of the participants in data analyses, but future works may take this characteristic into consideration and observe the difference in the effect of backpack weight or postural loading based on the physical performance of the participants.

Lastly, this study recruited participants in their 20s and 30s; future studies may recruit elderly as well as younger participants so as to understand the body-worn equipment weight (or postural loading) and age interaction effects.

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Appendix A. The ANOVA table for standing task

Table A.1 Visuo-spatial WM task score

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.807	5.930	5	.313	.890	.989

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	11.892	3	3.964	4.401	.006
	Greenhouse-Geisser	11.892	2.671	4.452	4.401	.009
	Huynh-Feldt	11.892	2.968	4.007	4.401	.006

Table A.2 Phonological loop WM task score

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.851	4.485	5	.482	.918	1.000

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	15.825	3	5.275	3.703	.015
	Greenhouse-Geisser	15.825	2.754	5.746	3.703	.018
	Huynh-Feldt	15.825	3.000	5.275	3.703	.015

Table A.3 Central executive WM task score

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.699	9.908	5	.078	.831	.916

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	10.292	3	3.431	11.723	.000
	Greenhouse-Geisser	10.292	2.493	4.127	11.723	.000
	Huynh-Feldt	10.292	2.747	3.747	11.723	.000

Table A.4 Sway area (V-S task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.199	44.691	5	.000	.532	.559

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	7391000.836	3	2463666.945	19.373	.000
	Greenhouse-Geisser	7391000.836	1.597	4626779.512	19.373	.000
	Huynh-Feldt	7391000.836	1.676	4410241.426	19.373	.000

Table A.5 Sway area (P-S task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.118	59.243	5	.000	.461	.477

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	5970894.545	3	1990298.182	11.210	.000
	Greenhouse-Geisser	5970894.545	1.384	4313170.043	11.210	.001
	Huynh-Feldt	5970894.545	1.431	4171245.568	11.210	.001

Table A.6 Sway area (C-S task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.466	21.180	5	.001	.721	.781

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	6919628.614	3	2306542.871	12.404	.000
	Greenhouse-Geisser	6919628.614	2.163	3199427.764	12.404	.000
	Huynh-Feldt	6919628.614	2.343	2953155.905	12.404	.000

Table A.7 Sway path (V-S task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.576	15.275	5	.009	.726	.787

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	215510.681	3	71836.894	11.901	.000
	Greenhouse-Geisser	215510.681	2.178	98970.129	11.901	.000
	Huynh-Feldt	215510.681	2.361	91282.100	11.901	.000

Table A.8 Sway path (P-S task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.383	26.609	5	.000	.606	.644

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	232242.852	3	77414.284	13.824	.000
	Greenhouse-Geisser	232242.852	1.818	127739.664	13.824	.000
	Huynh-Feldt	232242.852	1.933	120145.803	13.824	.000

Table A.9 Sway path (C-S task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.245	38.968	5	.000	.560	.590

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	232984.548	3	77661.516	12.707	.000
	Greenhouse-Geisser	232984.548	1.679	138748.715	12.707	.000
	Huynh-Feldt	232984.548	1.771	131581.639	12.707	.000

Table A.10 Sway variance_ML (V-S task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.433	23.236	5	.000	.724	.784

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	13977.854	3	4659.285	10.995	.000
	Greenhouse-Geisser	13977.854	2.171	6439.120	10.995	.000
	Huynh-Feldt	13977.854	2.353	5941.009	10.995	.000

Table A.11 Sway variance_ML (P-S task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.082	69.480	5	.000	.425	.436

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	13004.806	3	4334.935	7.049	.000
	Greenhouse-Geisser	13004.806	1.276	10192.748	7.049	.007
	Huynh-Feldt	13004.806	1.308	9938.811	7.049	.007

Table A.12 Sway variance_ML (C-S task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.254	38.004	5	.000	.600	.638

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	25216.496	3	8405.499	7.258	.000
	Greenhouse-Geisser	25216.496	1.801	14001.027	7.258	.002
	Huynh-Feldt	25216.496	1.913	13181.704	7.258	.002

Table A.13 Sway variance_AP (V-S task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.365	27.968	5	.000	.665	.714

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	70813.898	3	23604.633	15.413	.000
	Greenhouse-Geisser	70813.898	1.996	35483.074	15.413	.000
	Huynh-Feldt	70813.898	2.143	33043.665	15.413	.000

Table A.14 Sway variance_AP (P-S task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.216	42.447	5	.000	.537	.564

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	73860.160	3	24620.053	23.810	.000
	Greenhouse-Geisser	73860.160	1.612	45812.681	23.810	.000
	Huynh-Feldt	73860.160	1.693	43627.625	23.810	.000

Table A.15 Sway variance_AP (C-S task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.433	23.182	5	.000	.692	.746

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	80560.783	3	26853.594	15.112	.000
	Greenhouse-Geisser	80560.783	2.075	38828.836	15.112	.000
	Huynh-Feldt	80560.783	2.237	36006.135	15.112	.000

Table A.16 Heart rate (V-S task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.695	10.090	5	.073	.847	.935

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	607.758	3	202.586	10.057	.000
	Greenhouse-Geisser	607.758	2.541	239.148	10.057	.000
	Huynh-Feldt	607.758	2.806	216.600	10.057	.000

Table A.17 Heart rate (P-S task)

Mauchly's Test of Sphericity

Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.855	4.329	5	.503	.914	1.000

Tests of Within-Subjects Effects

Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	682.892	3	227.631	20.621	.000
	Greenhouse-Geisser	682.892	2.743	248.994	20.621	.000
	Huynh-Feldt	682.892	3.000	227.631	20.621	.000

Table A.18 Heart rate (C-S task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.776	7.032	5	.219	.850	.939

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	985.667	3	328.556	17.326	.000
	Greenhouse-Geisser	985.667	2.549	386.640	17.326	.000
	Huynh-Feldt	985.667	2.816	350.051	17.326	.000

Table A.19 Physical discomfort (V-S task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.257	37.677	5	.000	.547	.575

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	479.133	3	159.711	97.599	.000
	Greenhouse-Geisser	479.133	1.641	291.952	97.599	.000
	Huynh-Feldt	479.133	1.726	277.523	97.599	.000

Table A.20 Physical discomfort (P-S task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.352	28.970	5	.000	.598	.635

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	485.158	3	161.719	87.611	.000
	Greenhouse-Geisser	485.158	1.794	270.362	87.611	.000
	Huynh-Feldt	485.158	1.905	254.638	87.611	.000

Table A.21 Physical discomfort (C-S task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.487	19.953	5	.001	.713	.772

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	541.800	3	180.600	106.020	.000
	Greenhouse-Geisser	541.800	2.140	253.236	106.020	.000
	Huynh-Feldt	541.800	2.315	234.027	106.020	.000

Table A.22 Mental workload (V-S task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.378	26.936	5	.000	.617	.657

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	32.333	3	10.778	10.635	.000
	Greenhouse-Geisser	32.333	1.851	17.468	10.635	.000
	Huynh-Feldt	32.333	1.972	16.399	10.635	.000

Table A.23 Mental workload (P-S task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.575	15.358	5	.009	.738	.802

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	28.692	3	9.564	8.707	.000
	Greenhouse-Geisser	28.692	2.215	12.954	8.707	.000
	Huynh-Feldt	28.692	2.406	11.925	8.707	.000

Table A.24 Mental workload (C-S task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.603	14.033	5	.015	.732	.794

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	31.492	3	10.497	8.208	.000
	Greenhouse-Geisser	31.492	2.196	14.341	8.208	.000
	Huynh-Feldt	31.492	2.383	13.214	8.208	.000

Appendix B. The ANOVA table for navigating task

Table B.1 Visuo-spatial WM task score

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.769	7.287	5	.200	.839	.925

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	16.825	3	5.608	3.402	.021
	Greenhouse-Geisser	16.825	2.516	6.687	3.402	.029
	Huynh-Feldt	16.825	2.775	6.064	3.402	.024

Table B.2 Phonological loop WM task score

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.840	4.822	5	.438	.898	.999

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	1.092	3	.364	.197	.898
	Greenhouse-Geisser	1.092	2.694	.405	.197	.880
	Huynh-Feldt	1.092	2.996	.364	.197	.898

Table B.3 Central executive WM task score

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.829	5.213	5	.391	.906	1.000

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	5.100	3	1.700	3.707	.015
	Greenhouse-Geisser	5.100	2.718	1.876	3.707	.018
	Huynh-Feldt	5.100	3.000	1.700	3.707	.015

Table B.4 Tack completion time (V-N task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.379	26.864	5	.000	.644	.689

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	71.716	3	23.905	3.242	.026
	Greenhouse-Geisser	71.716	1.931	37.132	3.242	.048
	Huynh-Feldt	71.716	2.067	34.701	3.242	.044

Table B.5 Tack completion time (P-N task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.305	32.904	5	.000	.555	.585

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	87.153	3	29.051	7.956	.000
	Greenhouse-Geisser	87.153	1.666	52.324	7.956	.002
	Huynh-Feldt	87.153	1.755	49.663	7.956	.002

Table B.6 Gait speed (V-N task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.647	12.058	5	.034	.797	.874

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	.125	3	.042	6.554	.000
	Greenhouse-Geisser	.125	2.391	.052	6.554	.001
	Huynh-Feldt	.125	2.621	.048	6.554	.001

Table B.7 Gait speed (P-N task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.473	20.772	5	.001	.696	.751

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	.068	3	.023	4.847	.004
	Greenhouse-Geisser	.068	2.088	.033	4.847	.010
	Huynh-Feldt	.068	2.254	.030	4.847	.008

Table B.8 Gait speed (C-N task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.905	2.776	5	.735	.937	1.000

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	.042	3	.014	4.644	.005
	Greenhouse-Geisser	.042	2.810	.015	4.644	.006
	Huynh-Feldt	.042	3.000	.014	4.644	.005

Table B.9 Stride length (V-N task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.909	2.659	5	.753	.938	1.000

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	.125	3	.042	4.813	.004
	Greenhouse-Geisser	.125	2.815	.044	4.813	.005
	Huynh-Feldt	.125	3.000	.042	4.813	.004

Table B.10 Stride length (P-N task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.798	6.269	5	.281	.876	.972

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	.154	3	.051	10.674	.000
	Greenhouse-Geisser	.154	2.629	.058	10.674	.000
	Huynh-Feldt	.154	2.915	.053	10.674	.000

Table B.11 Stride length (C-N task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.919	2.344	5	.800	.947	1.000

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	.096	3	.032	7.487	.000
	Greenhouse-Geisser	.096	2.841	.034	7.487	.000
	Huynh-Feldt	.096	3.000	.032	7.487	.000

Table B.12 Heart rate (V-N task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.749	8.007	5	.156	.859	.950

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	781.967	3	260.656	10.133	.000
	Greenhouse-Geisser	781.967	2.578	303.329	10.133	.000
	Huynh-Feldt	781.967	2.851	274.245	10.133	.000

Table B.13 Heart rate (P-N task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.625	13.046	5	.023	.799	.876

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	858.300	3	286.100	14.365	.000
	Greenhouse-Geisser	858.300	2.398	357.900	14.365	.000
	Huynh-Feldt	858.300	2.629	326.435	14.365	.000

Table B.14 Heart rate (C-N task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.546	16.755	5	.005	.786	.860

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	1490.067	3	496.689	20.846	.000
	Greenhouse-Geisser	1490.067	2.358	631.816	20.846	.000
	Huynh-Feldt	1490.067	2.581	577.409	20.846	.000

Table B.15 Physical discomfort (V-N task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.182	47.296	5	.000	.542	.570

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	438.492	3	146.164	72.351	.000
	Greenhouse-Geisser	438.492	1.627	269.537	72.351	.000
	Huynh-Feldt	438.492	1.710	256.445	72.351	.000

Table B.16 Physical discomfort (P-N task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.393	25.912	5	.000	.630	.673

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	481.967	3	160.656	83.428	.000
	Greenhouse-Geisser	481.967	1.890	254.953	83.428	.000
	Huynh-Feldt	481.967	2.018	238.811	83.428	.000

Table B.17 Physical discomfort (C-N task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.524	17.892	5	.003	.682	.734

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	478.833	3	159.611	81.127	478.833
	Greenhouse-Geisser	478.833	2.045	234.101	81.127	478.833
	Huynh-Feldt	478.833	2.202	217.423	81.127	478.833

Table B.18 Mental workload (V-N task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.458	21.668	5	.001	.676	.727

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	31.200	3	10.400	9.856	.000
	Greenhouse-Geisser	31.200	2.029	15.380	9.856	.000
	Huynh-Feldt	31.200	2.182	14.297	9.856	.000

Table B.19 Mental workload (P-N task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.632	12.729	5	.026	.750	.816

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	34.625	3	11.542	9.597	.000
	Greenhouse-Geisser	34.625	2.250	15.390	9.597	.000
	Huynh-Feldt	34.625	2.448	14.141	9.597	.000

Table B.20 Mental workload (C-N task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Weight	.529	17.640	5	.003	.690	.743

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Weight	Sphericity Assumed	51.400	3	17.133	13.600	.000
	Greenhouse-Geisser	51.400	2.069	24.843	13.600	.000
	Huynh-Feldt	51.400	2.230	23.044	13.600	.000

Appendix C. Two-way ANOVA table

Table C.1 Visuo-spatial WM task score

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Physical task type	.909	2.680	2	.262	.916	.975
Weight	.794	6.390	5	.270	.876	.971
Interaction	.357	27.603	20	.121	.757	.915

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Physical task type	Sphericity Assumed	101.400	2	50.700	31.529	.000
	Greenhouse-Geisser	101.400	1.833	55.327	31.529	.000
	Huynh-Feldt	101.400	1.950	51.994	31.529	.000
Weight	Sphericity Assumed	41.742	3	13.914	10.649	.000
	Greenhouse-Geisser	41.742	2.628	15.881	10.649	.000
	Huynh-Feldt	41.742	2.914	14.324	10.649	.000
Interaction	Sphericity Assumed	12.333	6	2.056	1.664	.133
	Greenhouse-Geisser	12.333	4.544	2.714	1.664	.154
	Huynh-Feldt	12.333	5.493	2.245	1.664	.140

Table C.2 Phonological loop WM task score

Mauchly's Test of Sphericity

Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Physical task type	.928	2.092	2	.351	.933	.995
Weight	.765	7.415	5	.192	.839	.925
Interaction	.542	16.403	20	.694	.862	1.000

Tests of Within-Subjects Effects

Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Physical task type	Sphericity Assumed	5.172	2	2.586	1.078	.347
	Greenhouse-Geisser	5.172	1.866	2.772	1.078	.344
	Huynh-Feldt	5.172	1.989	2.600	1.078	.347
Weight	Sphericity Assumed	5.000	3	1.667	.809	.492
	Greenhouse-Geisser	5.000	2.516	1.987	.809	.474
	Huynh-Feldt	5.000	2.774	1.802	.809	.484
Interaction	Sphericity Assumed	13.450	6	2.242	1.495	.182
	Greenhouse-Geisser	13.450	5.170	2.602	1.495	.193
	Huynh-Feldt	13.450	6.000	2.242	1.495	.182

Table C.3 Central executive WM task score

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Physical task type	.917	2.422	2	.298	.923	.983
Weight	.760	7.622	5	.179	.833	.918
Interaction	.390	25.190	20	.197	.761	.920

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Physical task type	Sphericity Assumed	29.572	2	14.786	13.848	.000
	Greenhouse-Geisser	29.572	1.847	16.011	13.848	.000
	Huynh-Feldt	29.572	1.967	15.034	13.848	.000
Weight	Sphericity Assumed	17.431	3	5.810	14.801	.000
	Greenhouse-Geisser	17.431	2.499	6.975	14.801	.000
	Huynh-Feldt	17.431	2.753	6.331	14.801	.000
Interaction	Sphericity Assumed	2.713	6	.904	3.190	.028
	Greenhouse-Geisser	2.713	4.564	1.042	3.190	.034
	Huynh-Feldt	2.713	5.522	.941	3.190	.029

Table C.4 Heart rate (V-S, V-N and V-W tasks)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Physical task type	.934	1.912	2	.385	.938	1.000
Weight	.674	10.918	5	.053	.793	.868
Interaction	.408	24.017	20	.245	.810	.993

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Physical task type	Sphericity Assumed	99.739	2	49.869	.532	.590
	Greenhouse-Geisser	99.739	1.876	53.160	.532	.579
	Huynh-Feldt	99.739	2.000	49.869	.532	.590
Weight	Sphericity Assumed	2211.800	3	737.267	35.813	.000
	Greenhouse-Geisser	2211.800	2.378	930.257	35.813	.000
	Huynh-Feldt	2211.800	2.604	849.337	35.813	.000
Interaction	Sphericity Assumed	39.217	6	6.536	.296	.938
	Greenhouse-Geisser	39.217	4.862	8.066	.296	.911
	Huynh-Feldt	39.217	5.960	6.580	.296	.937

Table C.5 Heart rate (P-S, P-N and P-W tasks)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Physical task type	.879	3.601	2	.165	.892	.947
Weight	.528	17.713	5	.003	.732	.795
Interaction	.267	35.407	20	.019	.677	.802

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Physical task type	Sphericity Assumed	490.239	2	245.119	3.897	.026
	Greenhouse-Geisser	490.239	1.785	274.702	3.897	.031
	Huynh-Feldt	490.239	1.894	258.875	3.897	.028
Weight	Sphericity Assumed	2542.789	3	847.596	50.316	.000
	Greenhouse-Geisser	2542.789	2.197	1157.313	50.316	.000
	Huynh-Feldt	2542.789	2.385	1066.331	50.316	.000
Interaction	Sphericity Assumed	69.494	6	11.582	.755	.606
	Greenhouse-Geisser	69.494	4.064	17.099	.755	.558
	Huynh-Feldt	69.494	4.809	14.450	.755	.579

Table C.6 Heart rate (C-S, C-N and C-W tasks)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Physical task type	.807	6.006	2	.050	.838	.884
Weight	.756	7.751	5	.171	.873	.967
Interaction	.240	38.220	20	.009	.738	.887

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Physical task type	Sphericity Assumed	109.956	2	54.978	.512	.602
	Greenhouse-Geisser	109.956	1.676	65.592	.512	.571
	Huynh-Feldt	109.956	1.767	62.214	.512	.580
Weight	Sphericity Assumed	4067.178	3	1355.726	60.966	.000
	Greenhouse-Geisser	4067.178	2.618	1553.508	60.966	.000
	Huynh-Feldt	4067.178	2.901	1401.848	60.966	.000
Interaction	Sphericity Assumed	112.222	6	18.704	.876	.514
	Greenhouse-Geisser	112.222	4.428	25.345	.876	.489
	Huynh-Feldt	112.222	5.324	21.077	.876	.504

Table C.7 Physical discomfort (V-S, V-N and V-W tasks)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Physical task type	.894	3.124	2	.210	.905	.961
Weight	.084	68.708	5	.000	.441	.454
Interaction	.207	42.114	20	.003	.678	.802

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Physical task type	Sphericity Assumed	1.050	2	.525	.270	.764
	Greenhouse-Geisser	1.050	1.809	.580	.270	.742
	Huynh-Feldt	1.050	1.922	.546	.270	.756
Weight	Sphericity Assumed	1356.144	3	452.048	126.110	.000
	Greenhouse-Geisser	1356.144	1.323	1025.125	126.110	.000
	Huynh-Feldt	1356.144	1.362	995.939	126.110	.000
Interaction	Sphericity Assumed	11.306	6	1.884	2.212	.044
	Greenhouse-Geisser	11.306	4.066	2.781	2.212	.071
	Huynh-Feldt	11.306	4.811	2.350	2.212	.059

Table C.8 Physical discomfort (P-S, P-N and P-W tasks)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Physical task type	.912	2.587	2	.274	.919	.978
Weight	.231	40.565	5	.000	.522	.546
Interaction	.245	37.682	20	.010	.715	.854

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Physical task type	Sphericity Assumed	4.317	2	2.158	1.128	.331
	Greenhouse-Geisser	4.317	1.838	2.349	1.128	.328
	Huynh-Feldt	4.317	1.956	2.207	1.128	.330
Weight	Sphericity Assumed	1380.289	3	460.096	115.897	.000
	Greenhouse-Geisser	1380.289	1.565	882.252	115.897	.000
	Huynh-Feldt	1380.289	1.638	842.745	115.897	.000
Interaction	Sphericity Assumed	7.661	6	1.277	1.546	.166
	Greenhouse-Geisser	7.661	4.290	1.786	1.546	.189
	Huynh-Feldt	7.661	5.127	1.494	1.546	.177

Table C.9 Physical discomfort (C-S, C-N and C-W tasks)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Physical task type	.871	3.875	2	.144	.886	.939
Weight	.325	31.172	5	.000	.567	.598
Interaction	.340	28.919	20	.091	.739	.889

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Physical task type	Sphericity Assumed	12.572	2	6.286	3.210	.048
	Greenhouse-Geisser	12.572	1.771	7.099	3.210	.054
	Huynh-Feldt	12.572	1.878	6.695	3.210	.051
Weight	Sphericity Assumed	1406.853	3	468.951	126.222	.000
	Greenhouse-Geisser	1406.853	1.700	827.728	126.222	.000
	Huynh-Feldt	1406.853	1.794	783.993	126.222	.000
Interaction	Sphericity Assumed	12.406	6	2.068	2.386	.031
	Greenhouse-Geisser	12.406	4.434	2.798	2.386	.048
	Huynh-Feldt	12.406	5.333	2.326	2.386	.037

Table C.10 Mental workload (V-S, V-N and V-W tasks)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Physical task type	.739	8.468	2	.014	.793	.831
Weight	.286	34.683	5	.000	.559	.589
Interaction	.289	33.209	20	.033	.720	.861

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Physical task type	Sphericity Assumed	159.489	2	79.744	28.287	.000
	Greenhouse-Geisser	159.489	1.586	100.555	28.287	.000
	Huynh-Feldt	159.489	1.663	95.919	28.287	.000
Weight	Sphericity Assumed	106.344	3	35.448	29.006	.000
	Greenhouse-Geisser	106.344	1.677	63.424	29.006	.000
	Huynh-Feldt	106.344	1.768	60.157	29.006	.000
Interaction	Sphericity Assumed	4.156	6	.693	.912	.488
	Greenhouse-Geisser	4.156	4.317	.963	.912	.465
	Huynh-Feldt	4.156	5.166	.804	.912	.478

Table C.11 Mental workload (P-S, P-N and P-W tasks)

Mauchly's Test of Sphericity

Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Physical task type	.880	3.565	2	.168	.893	.948
Weight	.395	25.761	5	.000	.607	.646
Interaction	.339	28.961	20	.090	.773	.938

Tests of Within-Subjects Effects

Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Physical task type	Sphericity Assumed	12.867	2	6.433	1.992	.146
	Greenhouse-Geisser	12.867	1.786	7.202	1.992	.151
	Huynh-Feldt	12.867	1.896	6.787	1.992	.148
Weight	Sphericity Assumed	109.853	3	36.618	22.530	.000
	Greenhouse-Geisser	109.853	1.822	60.281	22.530	.000
	Huynh-Feldt	109.853	1.938	56.684	22.530	.000
Interaction	Sphericity Assumed	2.889	6	.481	.637	.701
	Greenhouse-Geisser	2.889	4.638	.623	.637	.660
	Huynh-Feldt	2.889	5.629	.513	.637	.691

Table C.12 Mental workload (C-S, C-N and C-W tasks)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Physical task type	.954	1.318	2	.517	.956	1.000
Weight	.398	25.548	5	.000	.663	.712
Interaction	.212	41.563	20	.003	.689	.818

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Physical task type	Sphericity Assumed	51.172	2	25.586	6.940	.002
	Greenhouse-Geisser	51.172	1.912	26.762	6.940	.002
	Huynh-Feldt	51.172	2.000	25.586	6.940	.002
Weight	Sphericity Assumed	107.711	3	35.904	22.030	.000
	Greenhouse-Geisser	107.711	1.990	54.130	22.030	.000
	Huynh-Feldt	107.711	2.136	50.424	22.030	.000
Interaction	Sphericity Assumed	5.006	6	.834	.825	.552
	Greenhouse-Geisser	5.006	4.135	1.211	.825	.515
	Huynh-Feldt	5.006	4.908	1.020	.825	.532

Appendix D. The ANOVA table for postural holding

Table D.1 Visuo-spatial WM task score

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Postural loading	.680	10.696	5	.058	.841	.927

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Postural loading	Sphericity Assumed	4.271	3	1.424	6.414	.001
	Greenhouse-Geisser	4.271	2.522	1.694	6.414	.001
	Huynh-Feldt	4.271	2.782	1.536	6.414	.001

Table D.2 Phonological loop WM task score

Mauchly's Test of Sphericity

Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Postural loading	.529	17.646	5	.003	.699	.755

Tests of Within-Subjects Effects

Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Postural loading	Sphericity Assumed	12.658	3	4.219	10.171	.000
	Greenhouse-Geisser	12.658	2.097	6.036	10.171	.000
	Huynh-Feldt	12.658	2.264	5.591	10.171	.000

Table D.3 Central executive WM task score

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Postural loading	.660	11.530	5	.042	.768	.838

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Postural loading	Sphericity Assumed	11.581	3	3.860	24.828	.000
	Greenhouse-Geisser	11.581	2.304	5.026	24.828	.000
	Huynh-Feldt	11.581	2.514	4.606	24.828	.000

Table D.4 Sway area (V-P task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Postural loading	.527	17.114	5	.004	.738	.804

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Postural loading	Sphericity Assumed	4341815.354	3	1447271.785	17.989	.000
	Greenhouse-Geisser	4341815.354	2.214	1960837.018	17.989	.000
	Huynh-Feldt	4341815.354	2.413	1799553.039	17.989	.000

Table D.5 Sway area (P-P task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Postural loading	.364	26.975	5	.000	.625	.668

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Postural loading	Sphericity Assumed	4411816.315	3	1470605.438	20.327	.000
	Greenhouse-Geisser	4411816.315	1.874	2354684.698	20.327	.000
	Huynh-Feldt	4411816.315	2.003	2202424.887	20.327	.000

Table D.6 Sway area (C-P task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Postural loading	.433	22.397	5	.000	.628	.672

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Postural loading	Sphericity Assumed	5034284.746	3	1678094.915	19.029	.000
	Greenhouse-Geisser	5034284.746	1.885	2670860.414	19.029	.000
	Huynh-Feldt	5034284.746	2.017	2496509.459	19.029	.000

Table D.7 Sway path (V-P task)

Mauchly's Test of Sphericity

Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Postural loading	.214	41.187	5	.000	.556	.586

Tests of Within-Subjects Effects

Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Postural loading	Sphericity Assumed	2729326.349	3	909775.450	43.437	.000
	Greenhouse-Geisser	2729326.349	1.667	1637684.881	43.437	.000
	Huynh-Feldt	2729326.349	1.759	1551293.222	43.437	.000

Table D.8 Sway path (P-P task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Postural loading	.172	47.053	5	.000	.564	.597

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Postural loading	Sphericity Assumed	3527436.204	3	1175812.068	32.993	.000
	Greenhouse-Geisser	3527436.204	1.693	2083965.790	32.993	.000
	Huynh-Feldt	3527436.204	1.790	1970766.014	32.993	.000

Table D.9 Sway path (C-P task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Postural loading	.111	58.805	5	.000	.484	.504

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Postural loading	Sphericity Assumed	3850079.786	3	1283359.929	43.026	.000
	Greenhouse-Geisser	3850079.786	1.452	2651149.376	43.026	.000
	Huynh-Feldt	3850079.786	1.511	2547970.595	43.026	.000

Table D.10 Sway maximal amplitude_ML (V-P task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Postural loading	.379	25.914	5	.000	.684	.739

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Postural loading	Sphericity Assumed	5107.326	3	1702.442	39.013	.000
	Greenhouse-Geisser	5107.326	2.051	2489.648	39.013	.000
	Huynh-Feldt	5107.326	2.216	2305.180	39.013	.000

Table D.11 Sway maximal amplitude_ML (P-P task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Postural loading	.517	17.627	5	.003	.687	.743

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Postural loading	Sphericity Assumed	4477.610	3	1492.537	25.306	.000
	Greenhouse-Geisser	4477.610	2.062	2171.652	25.306	.000
	Huynh-Feldt	4477.610	2.228	2009.585	25.306	.000

Table D.12 Sway maximal amplitude_ML (C-P task)

Mauchly's Test of Sphericity

Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Postural loading	.892	3.062	5	.691	.928	1.000

Tests of Within-Subjects Effects

Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Postural loading	Sphericity Assumed	4916.710	3	1638.903	40.573	.000
	Greenhouse-Geisser	4916.710	2.785	1765.654	40.573	.000
	Huynh-Feldt	4916.710	3.000	1638.903	40.573	.000

Table D.13 Sway maximal amplitude_AP (V-P task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Postural loading	.654	11.328	5	.045	.778	.854

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Postural loading	Sphericity Assumed	1264.920	3	421.640	7.421	.000
	Greenhouse-Geisser	1264.920	2.335	541.679	7.421	.001
	Huynh-Feldt	1264.920	2.561	493.971	7.421	.000

Table D.14 Sway maximal amplitude_AP (P-P task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Postural loading	.648	11.591	5	.041	.808	.891

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Postural loading	Sphericity Assumed	1355.630	3	451.877	6.938	.000
	Greenhouse-Geisser	1355.630	2.425	558.930	6.938	.001
	Huynh-Feldt	1355.630	2.672	507.337	6.938	.001

Table D.15 Sway maximal amplitude_AP (C-P task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Postural loading	.603	13.529	5	.019	.735	.800

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Postural loading	Sphericity Assumed	1349.045	3	449.682	6.972	.000
	Greenhouse-Geisser	1349.045	2.205	611.822	6.972	.001
	Huynh-Feldt	1349.045	2.401	561.776	6.972	.001

Table D.16 Heart rate (V-P task)

Mauchly's Test of Sphericity

Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Postural loading	.931	1.995	5	.850	.955	1.000

Tests of Within-Subjects Effects

Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Postural loading	Sphericity Assumed	2564.906	3	854.969	37.315	.000
	Greenhouse-Geisser	2564.906	2.864	895.571	37.315	.000
	Huynh-Feldt	2564.906	3.000	854.969	37.315	.000

Table D.17 Heart rate (P-P task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Postural loading	.755	7.786	5	.169	.861	.953

Tests of Within-Subjects Effects

Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Postural loading	Sphericity Assumed	3108.420	3	1036.140	31.037	.000
	Greenhouse-Geisser	3108.420	2.584	1202.816	31.037	.000
	Huynh-Feldt	3108.420	2.859	1087.153	31.037	.000

Table D.18 Heart rate (C-P task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Postural loading	.928	2.062	5	.841	.950	1.000

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Postural loading	Sphericity Assumed	5143.682	3	1714.561	49.392	.000
	Greenhouse-Geisser	5143.682	2.849	1805.717	49.392	.000
	Huynh-Feldt	5143.682	3.000	1714.561	49.392	.000

Table D.19 Physical discomfort (V-P task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Postural loading	.289	34.421	5	.000	.550	.578

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Postural loading	Sphericity Assumed	231.177	3	77.059	98.343	.000
	Greenhouse-Geisser	231.177	1.649	140.215	98.343	.000
	Huynh-Feldt	231.177	1.735	133.222	98.343	.000

Table D.20 Physical discomfort (P-P task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Postural loading	.509	18.707	5	.002	.674	.725

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Postural loading	Sphericity Assumed	275.076	3	91.692	110.803	.000
	Greenhouse-Geisser	275.076	2.022	136.010	110.803	.000
	Huynh-Feldt	275.076	2.175	126.476	110.803	.000

Table D.21 Physical discomfort (C-P task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Postural loading	.569	15.647	5	.008	.715	.773

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Postural loading	Sphericity Assumed	293.785	3	97.928	129.049	.000
	Greenhouse-Geisser	293.785	2.144	137.042	129.049	.000
	Huynh-Feldt	293.785	2.320	126.619	129.049	.000

Table D.22 Mental workload (V-P task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Postural loading	.553	16.419	5	.006	.735	.798

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Postural loading	Sphericity Assumed	23.582	3	7.861	25.326	.000
	Greenhouse-Geisser	23.582	2.204	10.698	25.326	.000
	Huynh-Feldt	23.582	2.393	9.854	25.326	.000

Table D.23 Mental workload (P-P task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Postural loading	.478	20.445	5	.001	.663	.711

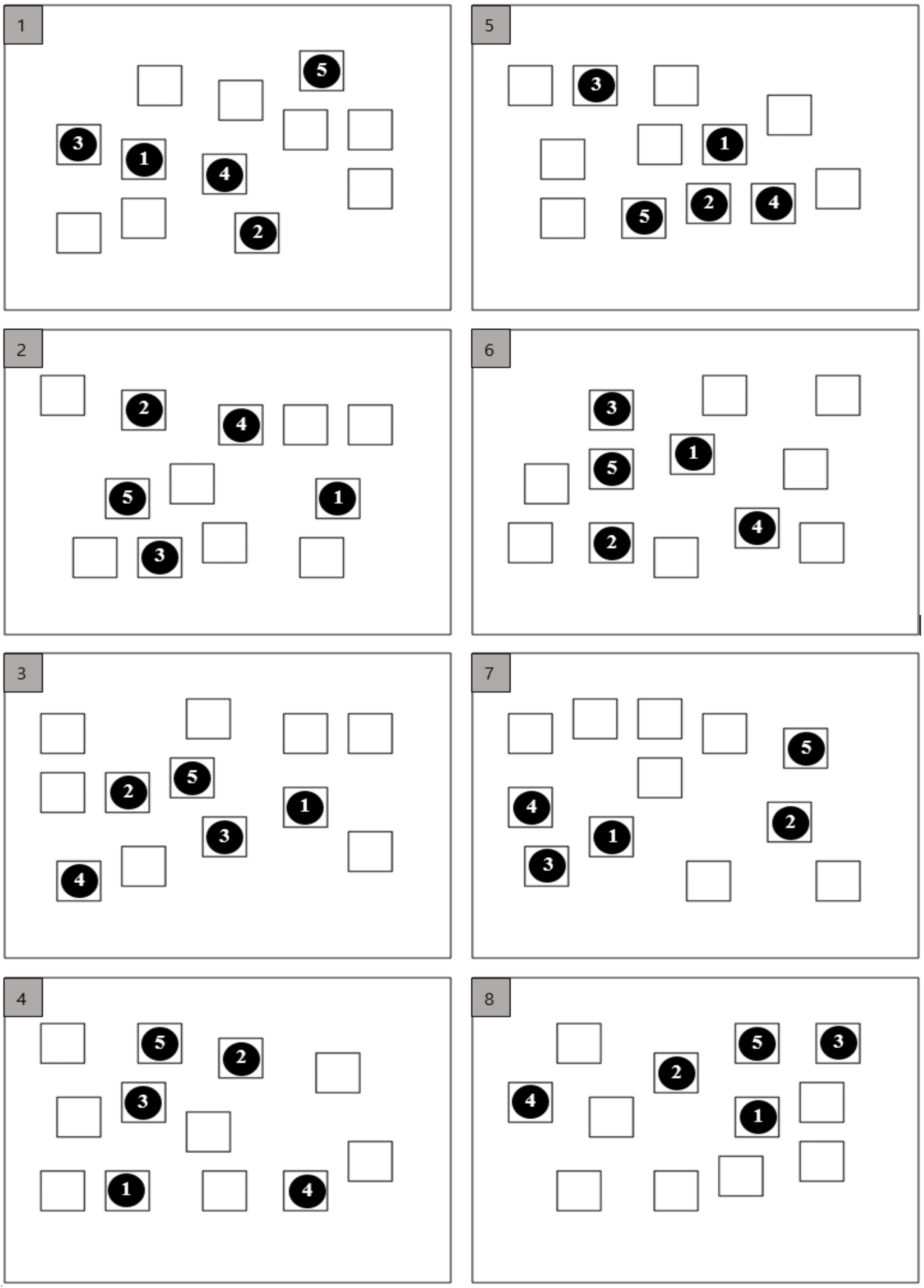
Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Postural loading	Sphericity Assumed	25.050	3	8.350	18.149	.000
	Greenhouse-Geisser	25.050	1.988	12.603	18.149	.000
	Huynh-Feldt	25.050	2.133	11.742	18.149	.000

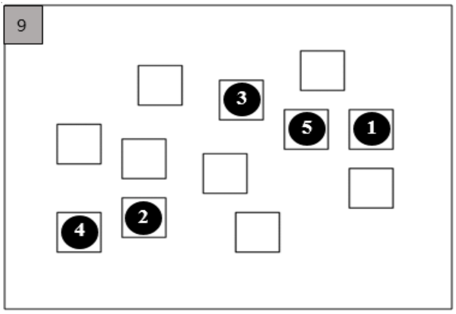
Table D.24 Mental workload (C-P task)

Mauchly's Test of Sphericity						
Within Subjects Effect	Mauchly's W	Approx. Chi-square	df	Sig.	Epsilon	
					Greenhouse-Geisser	Huynh-Feldt
Postural loading	.219	42.103	5	.000	.525	.550

Tests of Within-Subjects Effects						
Source		Type Ⅲ Sum of Squares	df	Mean Square	F	Sig.
Postural loading	Sphericity Assumed	25.171	3	8.390	21.402	.000
	Greenhouse-Geisser	25.171	1.575	15.985	21.402	.000
	Huynh-Feldt	25.171	1.650	15.259	21.402	.000

Appendix E. The Corsi block task

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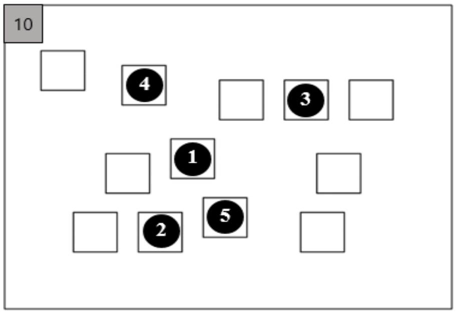
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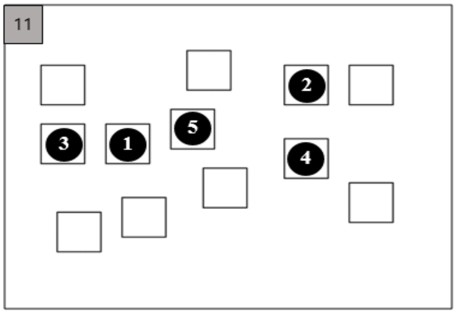
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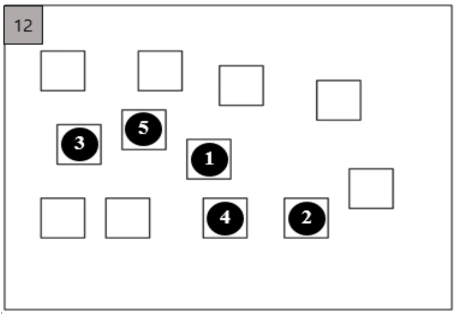
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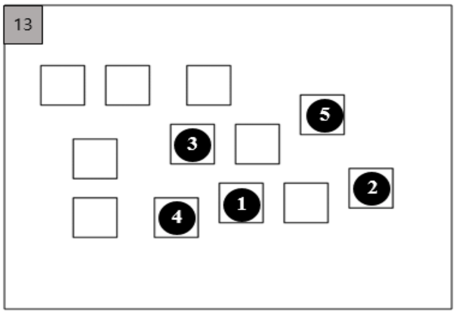
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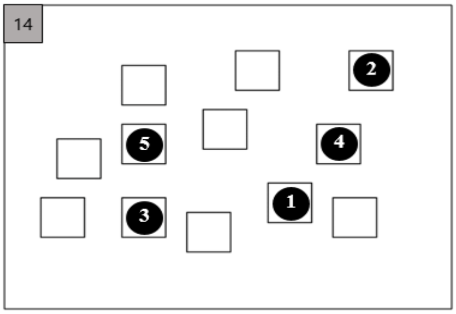
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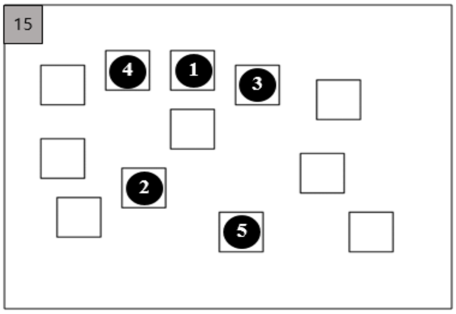
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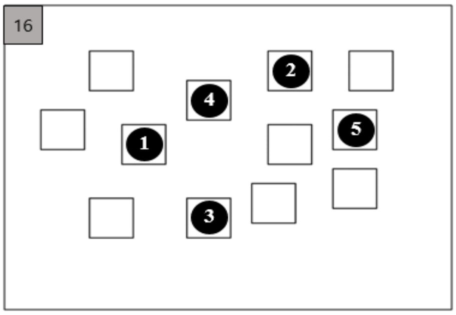
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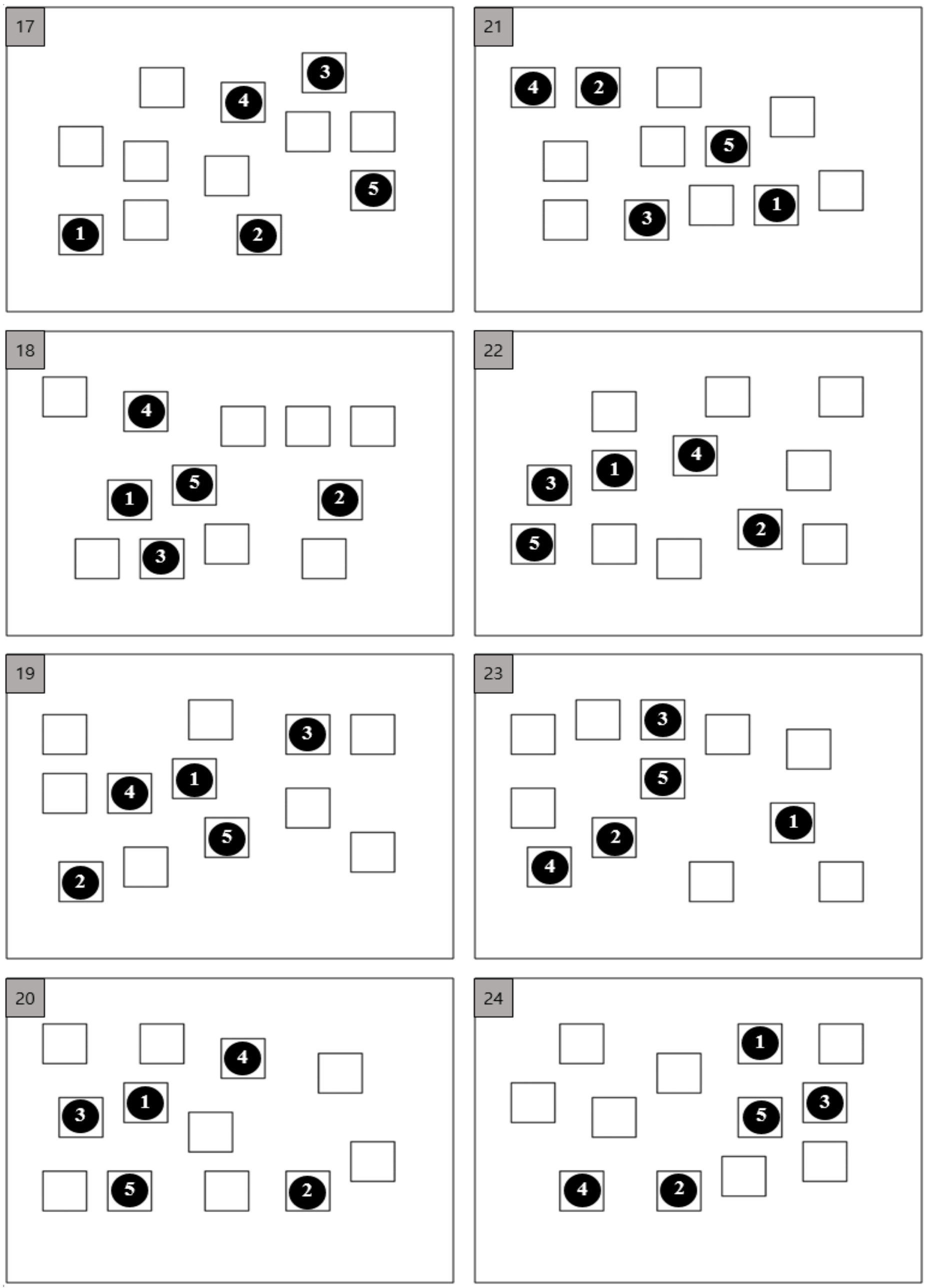

Figure E.1 The Corsi block task trials

Appendix F. The digit span task

Table F.1 The digit span task trials

	1	2	3	4	5	6	7	8	9	10
1	3	5	2	9	4	2	6	3	1	6
2	7	4	1	7	9	5	3	6	4	1
3	4	0	7	3	0	5	9	7	3	8
4	5	9	7	6	0	7	9	5	8	4
5	9	1	4	0	3	9	1	3	8	5
6	6	1	8	6	3	7	8	1	5	9
7	4	0	1	8	4	7	5	0	9	5
8	9	3	1	5	8	0	4	8	3	9
9	0	4	8	1	3	8	0	5	1	7
10	4	8	0	4	6	1	7	3	6	8
11	2	7	0	9	4	0	7	5	8	2
12	6	4	8	6	2	7	0	4	1	7
13	2	6	3	1	5	3	6	2	9	4
14	1	4	9	6	3	7	4	1	7	5
15	5	9	7	3	8	4	0	3	7	0
16	7	9	5	8	0	5	9	7	4	6
17	9	1	3	9	5	8	1	4	0	3
18	8	5	1	7	9	6	1	8	6	3
19	5	0	9	7	4	1	8	4	0	5
20	0	4	7	3	9	5	3	1	9	7
21	8	0	5	9	0	7	4	8	3	9
22	6	3	7	1	8	4	6	0	4	8
23	0	7	5	8	2	0	7	2	9	4
24	7	0	4	7	1	6	4	8	2	6

Appendix G. The 3-back task

Table G.1 The 3-back task trials

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Target number
1	1	4	8	3	8	7	2	6	5	7	4	7	0	3	9	7	7
2	5	7	3	2	6	0	6	4	9	1	3	6	8	2	6	2	6
3	4	1	9	0	5	2	3	2	9	8	1	4	2	9	1	2	2
4	6	0	8	7	9	5	3	2	3	9	7	5	3	1	9	3	3
5	1	3	9	4	5	0	5	1	6	2	8	5	4	7	5	6	5
6	9	5	2	3	8	9	7	8	0	1	3	9	8	4	8	5	8
7	7	9	2	6	2	5	1	0	1	7	3	6	1	6	8	1	1
8	2	8	4	1	0	1	3	1	0	5	0	3	9	6	7	0	0
9	4	2	5	1	7	0	8	7	3	2	3	9	5	7	0	7	7
10	0	3	9	2	4	1	5	4	6	0	7	2	4	6	4	8	4
11	4	6	0	3	0	9	2	5	7	9	4	9	3	1	2	9	9
12	1	5	8	4	8	6	3	6	0	9	5	6	0	7	6	2	6
13	6	4	7	1	8	9	3	2	9	6	0	7	5	9	3	9	9
14	9	1	0	5	3	2	9	4	2	4	1	6	7	2	5	2	2
15	4	7	3	9	1	0	2	5	1	6	1	7	3	2	1	7	1
16	7	3	2	5	2	8	1	5	9	8	1	8	4	7	4	8	8
17	7	1	9	6	8	0	4	0	5	3	1	6	0	6	8	0	0
18	2	9	7	1	5	0	5	4	7	9	3	5	1	4	5	9	5
19	3	5	8	1	7	4	3	7	6	4	2	4	8	0	5	4	4
20	4	8	5	0	3	6	2	8	0	6	4	6	3	9	2	6	6
21	2	6	0	7	3	5	9	4	3	1	3	0	5	8	3	4	3
22	8	2	7	3	9	5	1	5	8	4	9	6	5	3	9	5	5
23	9	6	1	0	7	5	4	9	7	2	7	5	9	3	7	4	7
24	7	0	5	9	4	1	5	1	4	9	4	8	5	0	1	4	4

국 문 초 록

군인, 소방관, 경찰 등을 포함한 많은 작업자들은 무거운 장비를 착용/소지한 상태에서 힘든 육체적 활동을 수행하게 된다. 예를 들어, 군인들의 경우에는 30-50kg에 육박하는 군장품목을 착용한 상태에서 장시간 서있거나 행군을 하며, 기타 여러 가지 자세를 취하거나 이동하는 과업을 수행하게 된다. 이와 같이 추가적인 하중이 부과되는 작업자들의 작업활동은 육체적 과업에 국한되지 않는다. 그들은 육체적 과업과 더불어 다양한 정신적 과업을 수행하게 된다 – 육체적 과업과 정신적 과업은 시간적으로 가깝게 또는 동시에 수행된다. 예를 들어, 군인들의 경우에는 전장상황 파악, 정보 교신, 의사 결정, 작전 명령 하달 및 수신 등을 포함한 정신적 과업을 수행한다.

이와 유사한 맥락으로 의사, 간호사, 약사 등과 같이 의료 분야에 종사하는 작업자들은 높은 수준의 정신적 부하와 더불어 육체적 부하가 가해지는 다중 과업을 빈번하게 수행한다. 예를 들어, 간호사들의 경우에는 긴급하고 분주한 작업 환경 하에서 여러 가지 정신적 과업을 수행하는 동시에 환자들을 침대 또는 지면으로부터 들어올리는 운반 작업과 같은 육체적 과업도 수행하게 된다.

위에 언급한 예시들과 같이, 많은 작업들은 육체적 요소(과업)와

정신적 요소(과업)로 구성되어 있다 – 순수하게 한 가지 요소만으로 이루어진 과업은 대단히 드문 것으로 보인다. 따라서, 작업자들은 그들의 과업을 수행함에 있어 육체적 부하와 정신적 부하를 동시에 경험하게 된다.

인간의 정보 처리(human information processing) 관점에서 볼 때, 과업을 구성하는 육체적 요소와 정신적 요소는 독립적이라기 보다는 상호 영향을 주고 받을 수 있는 것으로 보인다. 실제, 다수의 기존 연구들에서 상호 영향을 주는 관계가 경험적으로 증명된 바 있다. 이와 같이 동시에 수행되는 육체적 과업과 정신적 과업의 상호 연관성에 대한 기존 연구 결과들에 비추어 볼 때, 신체에 착용하는 장비의 무게(body-worn equipment weight) 또는 자세에 따른 부하(postural loading)가 작업자들의 정신적 과업 수행 능력에 영향을 미칠 수 있다는 가설을 생각해 볼 수 있다. 신체에 착용하는 장비의 무게 또는 자세에 따른 부하가 정신적 과업 수행 능력에 미치는 영향을 이해하는 것은 인간이 수행하는 과업의 안전성 및 성과를 극대화하는 작업 설계에 활용될 수 있을 것이다. 하지만, 이러한 중요성에도 불구하고 이러한 관계를 파악하는 연구는 드문 것으로 보인다.

따라서, 본 연구에서는 작업자들이 특정 육체적 과업을 수행하는 상황에서 신체에 착용하는 장비의 무게 또는 자세에 따른 부하가 작업기억 과업(working memory task) 수행능력에 미치는 영향을 실험적으로 살펴보았다. 이러한 목표를 달성하기 위해,

2가지 주요 연구가 수행되었다.

연구 1에서는 신체에 착용하는 장비의 무게가 작업기억 과업의 수행능력에 미치는 영향을 파악하였다. 이때, 군인과 소방관들을 포함한 많은 작업자들에 의해 널리 사용되는 배낭을 대표적인 신체 착용 장비로 선정하였다. 육체적 과업으로는 3가지(평평한 지면 위에 서 있는 과업, 특정 경로를 따라 걷는 과업, 직선 경로를 따라 걷는 과업)를 고려하였는데, 이는 군인과 소방관을 비롯한 많은 작업자들에 의해 수행되는 대표적인 육체적 과업이다. 또한, 3가지 종류의 작업기억 과업이 고려되었는데, 이는 작업기억의 3가지 세부 요소(시공간, 음운, 중앙집행기) 평가와 관련된 것이다. 데이터 분석 결과, 배낭 무게가 작업기억 과업의 수행 능력에 미치는 영향은 작업기억의 종류와 육체적 과업의 종류에 따라 다르게 나타났다. 전반적으로 살펴보면, 배낭 무게가 증가함에 따라 작업기억 과업 점수가 감소하는 경향을 나타내었다.

연구 2에서는 자세에 따른 부하가 작업기억 과업의 수행능력에 미치는 영향을 파악하였다. 육체적 과업의 경우에는 특정 자세를 일정 시간 동안 유지하는 과업이며, 부하 정도가 다른 4가지 자세 집단을 선정하였다. 작업기억 과업은 연구 1에서와 동일하게 3가지 종류를 고려하였다. 데이터 분석 결과, 자세에 따른 부하가 작업기억 과업의 수행능력에 영향을 미치는 것으로 나타났다. 다시 말해, 자세에 따른 부하가 증가함에 따라 3가지 종류의 작업기억 과업 점수가 모두 감소하였다.

본 연구의 결과는 장비 무게 또는 자세에 따른 부하를 줄이는 것이 작업자의 신체적 불편도와 근골격계 질환의 위험을 감소시키는데 기여할 뿐만 아니라 정신적 과업의 수행능력을 증가시킬 수 있음을 보여주었다. 이는 군인, 소방관, 조종사, 의료진들과 같이 부담이 큰 육체적 과업과 중요한 정신적 과업을 동시에 수행하는 환경에서 특히 중요하다고 볼 수 있다. 이러한 결과는 다중 과업이 요구되는 상황에서 사용되는 장비나 시스템을 설계함에 있어 정신적 과업 수행능력을 증가시키는데(또는, 수행능력 저하를 줄이는데) 활용될 수 있을 것으로 보인다. 또한, 본 연구의 결과는 육체적 과업과 정신적 과업이 동시에 수행되는 상황에서의 작업장 설계(work station design) 및 작업 자세의 개선에 도움이 되는 실험적 근거를 제공한다.

주요어: 배낭 무게, 자세에 따른 부하, 다중 과업, 정신적 과업 수행능력, 작업기억

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